Student Achievement Committee Meeting

Wednesday, August 19, 2026 7:00 PM
BOE - Room 36 and via Zoom Meeting Platform, 129 Church Street, Bristol, CT 06010

1.	**Call to Order/ Pledge of Allegiance**	
2.	**Decision: Approval of Minutes**	
3.	**Public Comment**	
4.	**Discussion: School Calendar**	
5.	**Information**	
5.1.	LAS 25-26 Outcomes	**Presenter:** Carly Fortin
5.2.	AP 2026 Outcomes	**Presenter:** Carly Fortin
6.	**Decision**	
6.1.	AP Cybersecurity Curriculum	**Presenter:** Laura Lanza and Logan Bourke
6.2.	AP Statistics Curriculum Revision	**Presenter:** Laura Lanza
6.3.	AP Chemistry Curriculum Revision	**Presenter:** Laura Lanza
7.	**Information: Curriculum and Instrutional Services Update, Summer 2026**	
8.	**Adjournment**	

Special Student Achievement & Outcomes Committee
May 27, 2026
MINUTES

The minutes presented within this document are a summary of the discussion that took place at the Student Achievement Committee meeting. To view the meeting in its entirety and hear full reports please go to: May 27, 2026 SAC Meeting Recording.

PRESENT Committee members: Kara Ledger, Barbara Tedesco, Robert Parenti

ALSO PRESENT: Ken Bagley (Zoom), Carly Fortin, Sara Hale, Laura Lanza, Sarah Lindstrom, Jessica Lemos, Zach Maher, Amy Martino, Mikayla Pascucci-Wallace (Zoom), Debra Vitale, Leszek Ward, Iris White

Call to Order
Commissioner Ledger called the meeting to order at 6:00 p.m.

Decision: Approval of Minutes from April 29,2026 meeting
On a motion made by Commissioner Parenti and seconded by Commissioner Tedesco, it was unanimously;
VOTED: to approve the April 29, 2026 Student Achievement minutes.

Public Comment: No public comment.

Information: Middle School Afterschool World Language Program
Dr. Sarah Lindstrom, World Language teacher, presented the success of a newly implemented middle school after-school language program that engaged both new learners and heritage speakers in Spanish, Italian, and Latin. The initiative aligns with the district's strategic goals to increase world language enrollment by 2030 and foster global communication, literacy, and empathy. While student engagement and confidence were high, Dr. Lindstrom noted that future iterations will focus on starting recruitment earlier to improve attendance and exploring sustainable funding options for expansion.

Questions and comments followed.

Decision: Grade 2 Mathematics Revision
Mrs. Debra Vitale, Elementary STEM Supervisor, presented revisions to the Grade 2 mathematics curriculum to align with the updated Illustrative Math 360 framework, which primarily focuses on deepening student strategies for addition and subtraction. The revised curriculum introduces new success criteria, embedded classroom support for multilingual and diverse learners, and translated family materials to enhance accessibility at home. Pending approval, the district has established a professional development schedule for teachers and administrators to unpack critical units and support effective classroom implementation.

DRAFT

Questions and comments followed.

On a motion made by Commissioner Parenti and seconded by Commissioner Tedesco, it was unanimously;
VOTED: to move the Grade 2 Math Curriculum Revision to the full Board of Education for approval.

Decision: Kindergarten Literacy Revision
Mr. Zachary Maher, Elementary Humanities Supervisor, presented revisions to the Kindergarten literacy curriculum to align with Connecticut's "Right to Read" legislation, shifting from isolated small-group instruction to a comprehensive, whole-group model rooted in the science of reading. The restructured daily schedule integrates phonemic awareness via Heggerty, explicit phonics through Wilson Fundations, and doubles the instructional time for Wit & Wisdom to 60 minutes to deepen comprehension across thematic science and social studies modules. To support this transition, the district will provide ongoing professional development, including modular planning sessions and "lab site" days featuring on-demand, real-time classroom coaching.

Questions and comments followed.

On a motion made by Commissioner Parenti and seconded by Commissioner Tedesco, it was unanimously;
VOTED: to move the Kindergarten Literacy Curriculum Revision to the full Board of Education for approval.

Decision: Grade 1 Literacy Revision
Mr. Maher presented the Grade 1 literacy curriculum revisions, which mirror the Kindergarten structure but scale up in complexity to focus on CVC words, suffixes, and vowel teams. The curriculum features five integrated thematic modules, including "A World of Books," "Creature Features," and international "Cinderella Stories," utilizing a 60-minute Wit & Wisdom block to engage all students in the same high-level, complex texts. Comments followed.

On a motion made by Commissioner Parenti and seconded by Commissioner Tedesco, it was unanimously;
VOTED: to move the Grade 1 Literacy Curriculum Revision to the full Board of Education for approval.

Decision: Academic Support Transition Grades 9-12, New Curriculum
Dr. Jessica Lemos and Mrs. Mikayla Pascucci-Wallace, Special Education Supervisors, presented a vertically aligned high school Special Education transition curriculum designed to guide students with IEPs toward post-secondary education, employment, and independent living. Structured around the 16 Connecticut Core Transition Skills for students aged 14 and older, the course repeats four thematic quarterly blocks—learning profiles, post-secondary pathways, life skills, and career building—with increasing complexity across grades 9 through 12. To track student success and satisfy state performance indicators, the curriculum builds a comprehensive student portfolio that culminates in a mandatory Summary of Performance upon graduation.

Questions and comments followed.

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On a motion made by Commissioner Parenti and seconded by Commissioner Tedesco, it was unanimously;
VOTED: to move the new Academic Support Transition Curriculum to the full Board of Education for approval.

Decision: Grade 7-8 Math Revision
Mrs. Laura Lanza, Secondary STEM Supervisor, presented comprehensive middle school math curriculum revisions to uniformly align all district courses under the Imagine Learning Illustrative Math 360 framework. The updated curriculum manages the vertical articulation of both the standard and accelerated pathways, paring down course content to set realistic instructional expectations and introducing a custom hybrid unit to ensure critical Grade 8 standards are given dedicated focus. To enhance day-to-day instruction and improve data tracking, the documents embed explicit universal design and multilingual language routines, while overhauling sectional checkpoints to serve as standardized, district-wide common formative assessments.

Comments followed.

On a motion made by Commissioner Parenti and seconded by Commissioner Tedesco, it was unanimously;
VOTED: to move the Grade 7-8 Math Curriculum Revision to the full Board of Education for approval.

There being no further discussion, Commissioner Ledger adjourned the meeting at 7:46pm.

Respectfully submitted,
Katlyne Laprise
Katlyne Laprise

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PROCEDURES FOR REMOTE PUBLIC COMMENT

Members of the public are invited to comment to the Board on any topic related to school business.

Items requiring consideration by the Board must be approved as an agenda item by a 2/3ds vote of the Board members present. Such items may be referred for further study and not necessarily acted upon at this meeting.

Anyone wishing to address the Board should adhere to the following procedures:

PUBLIC COMMENT

Before a Remote Meeting

1. Send your comments to: KatlyneLaprise@bristolk12.org
2. Be sure to put **PUBLIC COMMENT-SAC** in the subject line.
3. Include your name and address.
4. Direct your comments to the Board Chair.
5. Your comments will be read at the meeting by the Board Chair.
6. All comments should be written in an appropriate manner, particularly if concerning a personnel matter.
7. Any comments not adhering to the guidelines will not be read at the meeting.

During a Remote Meeting

1. Everyone is requested to address the Chair for recognition.
2. Each speaker must state his/her name and address.
3. All speakers must observe rules of common etiquette. Personalities are not to be injected. Anyone violating this rule will be denied the floor. Unless waived by the Chairperson or a majority of the Board,
4. Each speaker shall limit his/her remarks to three (3) minutes.
5. A speaker will not be recognized for a second time on the same topic.
6. Each speaker must concern himself/herself with the topic under discussion. Anyone digressing from the topic will be ruled out of order.
7. Written statements and materials may be made available, in advance of comments, for distribution to Board members.
8. Speakers shall state their positions on the subject being discussed.
9. Board members will not respond directly to comments during the Board meeting. The Superintendent will direct the question to the appropriate staff member for follow-up.

Bristol Public Schools

Bristol, Connecticut

Course Title:	Content Area:	Grade Level:	Credit (if applicable)
AP Cybersecurity	CTE	10-12	1.0

Course Description:

The AP Cybersecurity course provides a broad introduction to the field, aligning closely with a standard first-year collegiate introductory cybersecurity course. The course is designed to train students to:

- Understand Risk: Students learn about common threats and vulnerabilities and how they combine to create risk for individuals and organizations.
- Apply Defense-in-Depth: A central focus is studying how risk can be mitigated through a defense-in-depth strategy, which implements layered security controls.
- Secure Multiple Domains: Students explore specific vulnerabilities, attacks, mitigations, and detection measures across several key domains, including:
  - Physical spaces
  - Computer networks
  - Digital devices
  - Applications and data
- Evaluate Societal Impact: Throughout their studies, students consider the broader impact of cybersecurity on individuals, organizations, societies, and governments.

AP developed the course in partnership with college faculty and industry leaders, the course also aligns with the NICE Workforce Framework*. It emphasizes hands-on learning through authentic unit scenarios that connect classroom knowledge to real-world professional tasks.

**The NICE Workforce Framework for Cybersecurity, commonly referred to as the NICE Framework is developed by the National Institute for Standards and Technology (NIST) under the U.S. Department of Commerce. It is a nationally focused resource to help employers develop their cybersecurity workforce and it establishes a common lexicon that describes cybersecurity work and workers regardless of where or for whom the work is performed. The NICE Framework applies across public, private, and academic sectors. https://niccs.cisa.gov/tools/nice-framework*

Aligned Core Resources:	Connection to the ***BPS Vision of the Graduate***

• AP Cybersecurity Course and Exam Description
• AP Classroom: A dedicated online platform that provides a variety of resources and tools to offer yearlong support and meaningful feedback on student progress. These resources include:
  ○ Unit Guides
  ○ Lesson Plans
  ○ Professional Skills and Collaboration Rubrics
  ○ Practice Tests
  ○ Data Reports
  ○ Unit Scenarios
	Successfully Employ Skills for Self-Sufficiency
	• Goal Directed: As a "Career Kickstart" course, it prepares students for high-skill, high-growth careers by aligning with the NICE Workforce Framework. By earning an employer-endorsed credential, students demonstrate the ability to determine a career path that leads to self-sufficiency.
	Meaningfully Contribute to a Global Society
	• Collaboration: Collaboration is a core skill category (Category 4) in the AP framework. Students must work effectively with diverse teams to develop shared team objectives, determine clear roles, and assume responsibility for collaborative tasks.
	• Global Awareness: The course requires students to consider the impact of cybersecurity on societies and governments. This connects to the Vision of the Graduate's emphasis on understanding the global implications of decisions and staying informed about governmental processes and legal regulations like the Privacy Act of 1974.
	Effectively Communicate in a Global Society
	• Communication: Students must articulate thoughts effectively by explaining key cybersecurity concepts and communicating solutions to technical problems in both written and oral forms.
	• Information and Media Literacy: The course develops students' abilities to assess the credibility of sources, analyze digital messages, and identify phishing tactics. Students learn the ethical and legal issues surrounding the use of media and sensitive information.
	• Technology Literacy: Students use digital technology and networks (firewalls, VPNs, and Linux-based systems) to access, manage, and evaluate information, which is central to functioning in a modern knowledge society.

	Demonstrate Academic Knowledge and Skills • Content Mastery: Students develop a baseline understanding of academic disciplines within the Bristol curriculum by mastering introductory college-level cybersecurity content. • Critical Thinking and Problem Solving: The framework is an "unflinching encounter with evidence," requiring students to analyze risk, solve authentic problems through unit scenarios, and reflect critically on learning processes and solutions.
Additional Course Information: ***Knowledge/Skill Dependent courses/prerequisites***	**Link to *Completed Equity Audit***
There are no specific course prerequisites for AP Cybersecurity. The curriculum is designed with the following expectations regarding student readiness and course alignment: • Skill Requirements: Success in the course relies heavily on collaboration skills, which are considered critical to the deep understanding and application of cybersecurity knowledge. • Course Alignment: AP Cybersecurity is designed to be the equivalent of a one-semester introductory college course in cybersecurity. It is a part of the Career and Technical Education (CTE) Digital Technology cluster. • Foundational Knowledge: Unit 1 provides a starting point for all students, no prior technical security knowledge is required to begin the course.	AP Cybersecurity

Standard Matrix

Skill Standard	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5
Skill 1: Analyze Risk - Evaluate risk to organizational assets.					
1.A Identify, with and without the support of AI, vulnerabilities, threats, and attack methods, and explain how they generate risk.	X				
1.B Determine ways adversaries exploit vulnerabilities to compromise an asset.	X				
1.C Evaluate, with and without the support of AI, the likelihood and impact of risks.			X	X	
1.D Document, with and without the support of AI, the likelihood and impact of risks.			X	X	
Skill 2: Mitigate Risk - Implement protective and deterrent security controls.					
2.A Identify security controls, and explain how they mitigate risks.	X	X	X	X	X
2.B Determine layered security controls that address vulnerabilities.		X		X	X
2.C Evaluate, with and without the support of AI, the impact of protective risk-management strategies.			X	X	
2.D Implement and log mitigations with and without the support of AI.			X	X	X
Skill 3: Detect Attacks - Implement detection methods, monitor systems, and analyze evidence.					
3.A Identify methods for monitoring systems, and explain how they detect attacks.	X	X			
3.B Determine strategies and methods to detect attacks.		X			X
3.C Evaluate the impact of threat detection methods.			X		
3.D Detect and classify cyberattacks by analyzing digital evidence with and without the support of AI.					X
Skill 4: Collaborate - Work with others and AI to accomplish a task.					
4.A Develop clear, shared team objectives related to a	X	X	X	X	X

cybersecurity task.					
4.B Determine clear roles and responsibilities for members of a team working to accomplish a cybersecurity task.	X	X	X	X	X
4.C Implement AI as a collaboration tool individually and as a group.	X	X	X	X	X
4.D Complete assigned work to accomplish a collaborative cybersecurity task.	X	X	X	X	X

Unit Links

Unit 1: Introduction to Security
Unit 2: Securing Spaces
Unit 3: Securing Networks
Unit 4: Securing Devices
Unit 5: Securing Applications and Data

Unit Title:

Unit 1: Introduction to Security

Relevant Standards:

Skill 1: Analyze Risk - Evaluate risk to organizational assets.

1.A Identify, with and without the support of AI, vulnerabilities, threats, and attack methods, and explain how they generate risk.

1.B Determine ways adversaries exploit vulnerabilities to compromise an asset.

Skill 2: Mitigate Risk - Implement protective and deterrent security controls.

2.A Identify security controls, and explain how they mitigate risks.

Skill 3: Detect Attacks - Implement detection methods, monitor systems, and analyze evidence.

3.A Identify methods for monitoring systems, and explain how they detect attacks.

Skill 4: Collaborate - Work with others and AI to accomplish a task.

4.A Develop clear, shared team objectives related to a cybersecurity task.

4.B Determine clear roles and responsibilities for members of a team working to accomplish a cybersecurity task.

4.C Implement AI as a collaboration tool individually and as a group.

4.D Complete assigned work to accomplish a collaborative cybersecurity task.

Essential Question(s):	**Enduring Understanding(s):**
• How do adversaries use social engineering to manipulate human behavior, and what are the potential impacts of these tactics? • In what ways do adversaries exploit weak authentication to compromise systems, and how can individuals strengthen their authentication to protect themselves? • What are the specific hazards associated with using public Wi-Fi networks, and what actions can individuals take to protect sensitive data while online? • How can adversaries leverage AI-powered tools to augment cyberattacks through impersonation or more convincing phishing? • How can cyber defenders use AI-powered tools to enable faster and more accurate threat detection and response? • How do the skill level and motivation of an adversary influence the nature of a cyberattack?	• Adversaries use social engineering and psychological tactics to manipulate human behavior, tricking individuals into revealing sensitive information or compromising their own security. • Systems are frequently compromised through weak authentication; however, individuals can significantly mitigate this risk by using multifactor authentication (MFA) and password managers to create long, unique, and random credentials. • Public Wi-Fi networks present unique hazards, such as evil twin and jamming attacks, where adversaries can capture network traffic or cause a denial of service (DoS). Protection requires verifying network authenticity and using virtual private networks (VPNs) to encrypt traffic. • Artificial Intelligence significantly augments the cybersecurity landscape. Adversaries use AI for voice cloning, digital avatars, and creating convincing phishing messages. Conversely, cyber defenders leverage AI to analyze millions of digital events at a scale impossible for humans, enabling faster and more accurate threat detection and response. • System vulnerabilities provide avenues for attack, and the resulting risk is a combination of the likelihood of an attack and the potential impact. • Cyberattacks can be identified by monitoring systems for indicators of compromise, such as unusual login times, failed authentication attempts, or suspicious network traffic logs.
Demonstration of Learning:	**Pacing for Unit**
Authentic unit scenarios designed to connect cybersecurity concepts to real-world personal security situations (see Lesson Sequence). Formal demonstration of learning is measured through multiple-choice questions on the AP Exam. Cumulative learning is measured through multiple-choice	5 Block Periods 1 Topic per Day • Topic 1.1: Understanding Social Engineering • Topic 1.2: Suspicious Website Logins • Topic 1.3: Best Practices for Public Networks • Topic 1.4: AI-Based Cybersecurity Attacks • Topic 1.5: Leveraging AI in Cyber Defense

questions on the AP Exam, which weigh Skill Category 1 (Analyze Risk), Skill Category 2 (Mitigate Risk), and Skill Category 3 (Detect Attacks) equally at 25–40% each across the entire course content.	
Family Overview (link below)	**Integration of Technology:**
AP Cybersecurity Family Overview	• Generative AI • Large Language Models (LLMs) • Multifactor Authentication (MFA) • Password Managers • Virtual Private Networks (VPNs) • Public Wi-Fi and Encryption • Wi-Fi router authorization logs
Unit-specific Vocabulary:	**Aligned Unit Materials, Resources, and Technology (beyond core resources):**
• Social engineering • Elicitation • Intimidation • Urgency • One-time password (OTP) • Multifactor authentication (MFA) • Password manager • Indicators of compromise (IoC) • Zero day • Evil twin attack • Jamming attack • Denial of service (DoS) • War driving • Virtual private network (VPN) • Generative AI / Large Language Models (LLMs) • Digital avatar • Shared secrets • Probabilistic calculations • Training sets	N/A
Opportunities for Interdisciplinary Connections:	**Anticipated misconceptions:**
• Human Behavior: Students explore how adversaries leverage common psychological principles to influence targets. • Emotional Manipulation: The curriculum covers the use of intimidation (leveraging a natural human aversion to negative consequences) and urgency (exploiting the impulse to react quickly to time-sensitive needs) to manipulate victims into bypassing their normal safety considerations. • Data Privacy Laws: Instruction is expected to integrate federal regulations such as the Privacy Act of 1974, the Children's Online Privacy Protection Act (COPPA), and the Health Insurance Portability and Accountability Act (HIPAA). • Professional Norms: The course connects to ethics by sharing norms from professional organizations like ISC2 and the UK Cyber Security Council. • Industry Regulation: Connections can be made to business and finance through the Payment Card Industry Data Security Standard (PCI DSS), which regulates the security of credit card data.	• Adversaries on a public Wi-Fi network can read all of a user's traffic. • Using a Virtual Private Network (VPN) makes a user's activity completely private from everyone. • Artificial Intelligence (AI) will replace the need for human cybersecurity professionals. • Phishing attempts are always easy to identify because of poor grammar or unnatural language. • If a system uses voice or image-based authentication, it is immune to remote impersonation. • AI tools like chatbots are safe places to enter any data for analysis. • Absolute security can be achieved if the right tools are used.

• Probability: AI-powered threat detection tools rely on probabilistic calculations to report the likelihood that a digital event is malicious. • Generative AI: Students study Large Language Models (LLMs) and how their training sets can be poisoned with false information, which connects to data science and linguistics. • Adversary Motivations: Students identify different types of adversaries whose motivations may be political, ideological, or belief-based. • Societal Impact: The unit encourages students to consider how cybersecurity affects societies and governments, particularly regarding the protection of sensitive public data and infrastructure.	
Connections to Prior Units:	**Connections to Future Units:**
N/A	• In Unit 2 (Securing Spaces), students are expected to practice selecting physical security controls based on the principles from Unit 1. • The core strategy of defense-in-depth, which focuses on layered security controls, is a recurring theme that students apply to networks in Unit 3, devices in Unit 4, and applications in Unit 5. • Risk Assessment: Unit 1 introduces identifying vulnerabilities and potential avenues of attack. This matures into formal risk assessment processes in Unit 2 (Topic 2.1) and is applied to complex network and device scenarios in Units 3 and 4. • Indicators of Compromise (IoCs): The concept of detecting attacks by analyzing log files for signs of suspicious activity (IoCs) begins in Unit 1 with unauthorized logins (Scenario 1B). This skill is built upon in Unit 3 for network attacks, Unit 4 for device password attacks, and Unit 5 for application-level attacks like SQL injection. • Authentication: The basic principles of strong authentication and multifactor authentication (MFA) from Topic 1.2 are expanded in Unit 4, where students learn the technical details of hashing and salt. • Artificial Intelligence (AI): The dual-use nature of AI for attack and defense introduced in Topics 1.4 and 1.5 is revisited in Unit 3, where students evaluate how AI-powered tools enable faster, more accurate detection on massive enterprise networks. • Encryption and VPNs: The individual use of VPNs and protocol sensitivity discussed in Unit 1 (Topic 1.3) sets the stage for the formal study of cryptography, symmetric vs. asymmetric encryption, and organizational VPN policies in Units 3 and 5.

Differentiation through *Universal Design for Learning*

	Engagement	Representation	Action & Expression
1.1A	"Can You Spot the Phish?" gamified challenge analyzing real and simulated email/SMS lures.	Color-coded infographic highlighting red flags (urgent tone, mismatched domain, generic greeting).	Create an annotated "Phishing Anatomy" breakdown poster or record a screencast walkthrough.
1.1B	Role-play exercise simulating social engineering tactics like urgency and authority.	Mind map illustrating psychological triggers (fear, scarcity, trust, authority).	Write a psychological case analysis or record a podcast episode on why victims comply.

1.1C	Real-world breach case studies exploring individual and corporate fallout.	Dual-column matrix categorizing impacts across financial, operational, and reputational scales.	Present a news broadcast report or draft an executive breach impact summary.
1.2A	Interactive password-cracking time estimator demonstrating brute-force speeds.	Flowchart comparing brute-force, dictionary, and credential stuffing attack mechanisms.	Design a password safety awareness flyer or construct an interactive quiz.
1.2B	"Crack the Default" challenge attempting login on default credentials in isolated VMs.	Step-by-step graphic showing entry points via weak, reused, or unhashed passwords.	Write an IT advisory memo or draw an explanatory technical comic strip.
1.2C	Hands-on experience setting up Multi-Factor Authentication (MFA) and password managers.	Layered graphic illustrating authentication factors (Something you know, have, are).	Draft a personal password policy guide or produce an MFA video tutorial.
1.3A	Threat actor card-sorting game matching motives, tools, and targets.	Continuum chart mapping threat actors from script kiddies to nation-states.	Create a threat actor dossier portfolio or record a mock intelligence briefing.
1.3B	Interactive simulation of Evil Twin access points and packet eavesdropping.	Network topology diagram showing Evil Twin, Jamming, and MitM attack vectors.	Design a public Wi-Fi security checklist or demonstrate wireless threat mitigations.
1.3C	Scenario-based "Remote Worker Challenge" securing public Wi-Fi connections.	Visual guide detailing VPN encryption, auto-connect settings, and HTTPS enforcement.	Produce an employee travel safety video or draft a remote work wireless policy.
1.4A	Audio and video analysis of AI voice cloning and deepfake phishing examples.	Comparative visual showing traditional phishing vs. AI-driven spear-phishing.	Write an analytical essay or record a video reflection on AI attack scaling.
1.4B	"Outsmart the AI" challenge enforcing out-of-band verification protocols.	Process map showing multi-channel identity verification and cryptographic checks.	Build an organizational verification decision tree or record a training video.
1.5A	Test automated static code analyzers and AI security review tools.	Workflow visual showing parallel manual and AI automated code analysis.	Write a comparative analysis report or present a live demonstration of AI code scanning.
1.5B	Anomaly detection game identifying statistical outliers in network traffic datasets.	Visual graph contrasting baseline user behavior with anomaly probability thresholds.	Construct a technical slide deck or present an interactive probability model.

Supporting Multilingual/English Learners (*CELP standards*)

	Emerging	Expanding	Bridging
1.1A	Select or circle visual examples/phishing red flags (e.g., suspicious sender, urgent language) from a given sample email using a bilingual word bank.	Highlight and label social engineering red flags in sample emails/texts, explaining in complete sentences using sentence starters (*"The indicator is ____ because ____"*).	Identify and categorize subtle indicators of social engineering in multi-stage attack scenarios, explaining reasoning in technical prose.
1.1B	Match social engineering psychological triggers (e.g., *urgency, fear, authority*) to visual scenarios using graphic organizers.	Explain the victim influence cycle using guided paragraph frames (*"Attackers use [trigger] to make victims feel [emotion], which leads them to [action]"*).	Draft a detailed analysis explaining how combined psychological triggers manipulate human behavior in corporate settings.
1.1C	Identify and sort impact icons (e.g., *financial loss, data theft, reputation damage*) into cause-and-effect visual charts.	Write short paragraph descriptions of attack consequences using transition words (*as a result, consequently, leads to*).	Compose a comprehensive impact assessment detailing short-term and long-term organizational and personal consequences.
1.2A	Match password attack descriptions (e.g., *brute force, credential stuffing*) to illustrative diagrams or log entry snippets using a glossary.	Identify signs of password attacks in log snippets using key vocabulary (*failed attempts, lockouts, rate limiting*).	Synthesize multiple system log entries to detect and distinguish between brute force, dictionary, and spray password attacks.
1.2B	Complete cloze (fill-in-the-blank) sentences describing weak password exploitation using word banks and diagrams.	Explain exploitation mechanisms using cause-and-effect sentence frames (*"Adversaries exploit [weakness] by [action], which results in [compromise]"*).	Formulate a technical explanation detailing how adversaries bypass single-factor or weak authentication systems.

1.2C	Label multi-factor authentication (MFA) components (e.g., *something you know, have, are*) on a visual diagram.	Explain how MFA and password managers increase security using comparative sentence frames (*"MFA is stronger than passwords alone because..."*).	Compare and justify complex authentication architecture enhancements (e.g., FIDO2/WebAuthn, biometric policies) in an executive summary.
1.3A	Classify adversary profiles into a T-chart (*Low-Skilled / Script Kiddie* vs. *High-Skilled / APT*) using provided trait cards.	Write comparative statements distinguishing adversary skill levels based on motivation, tools, and resources using graphic organizers.	Analyze complex threat intelligence briefs to identify, classify, and profile adversary skill levels and sophistication.
1.3B	Match terms (e.g., *evil twin, rogue AP, jamming*) to visual illustrations of wireless network topologies.	Describe wireless attack mechanisms using sequence frames (*"First, the attacker sets up... Next, the user connects..."*).	Evaluate wireless threat vectors in various physical environments and document specific attack signatures.
1.3C	Match protective actions (e.g., *use VPN, disable auto-connect*) to corresponding wireless threats using icon cards.	Describe recommended wireless security measures in written paragraphs using advisory language (*"Users should...", "Organizations must..."*).	Develop and justify a comprehensive wireless security protocol for remote and mobile workers.
1.4A	Identify examples of AI-augmented attacks (e.g., *voice cloning, automated phishing*) using side-by-side visual comparisons.	Explain how AI enhances attack speed and scale using graphic organizers and cause-and-effect prompts.	Analyze complex AI threat scenarios (e.g., deepfakes, AI-generated polymorphic code) and articulate adversary capabilities.
1.4B	Sequence visual steps for verifying AI-driven communications (e.g., *out-of-band verification, authentication phrase*).	Summarize countermeasures against AI-driven attacks using structured writing frames (*"To defend against AI voice cloning, organizations can..."*).	Critically evaluate defense mechanisms against advanced AI threat vectors and propose multi-layered mitigation strategies.
1.5A	Match AI defensive capabilities (e.g., *automated code auditing, anomaly detection*) to simple definitions using a visual glossary.	Explain defensive AI applications in structured paragraphs using targeted academic language (*analyze, detect, automate, audit*).	Write a detailed proposal outlining how AI tools can be integrated into continuous integration/continuous deployment (CI/CD) pipelines for security.
1.5B	Order a simplified flow chart showing data input $\rightarrow$ probabilistic calculation $\rightarrow$ threat alert.	Explain probabilistic threat scoring using guided prompts (*"AI calculates probability by comparing [baseline] to [anomaly]..."*).	Mathematically and conceptually explain how machine learning models utilize baseline behavior metrics to reduce time-to-detect (TTD).

Unit Outline

Lesson Sequence	Learning Target	Success Criteria	Assessment
DAY 1 1.1 Understanding Social Engineering	**1.1.A:** Identify common indicators of social engineering tactics.	Attacks use psychological tactics (elicitation) to manipulate users into revealing data or clicking malicious links/files. Tactics include intimidation (threats of negative consequences) and urgency (pressure to act quickly).	**Scenario 1A:** Detecting Phishing Messages Students can analyze a simulated email to identify psychological triggers like urgency and intimidation and describe the potential impact of clicking malicious links.
	1.1.B: Explain how social engineering tactics influence victims.	Tactics rely on psychological principles influencing human behavior. Intimidation uses fear and aversion to negative outcomes. Urgency prevents users from taking time to consider if an action is safe or reasonable.	
	1.1.C: Describe possible impacts of attacks.	Disclosure of personal info leading to impersonation or compromised challenge questions. Disclosure of one-time passwords (OTP) or login codes.	

		Installation of malware or capture of credentials via fake websites.	
DAY 2 1.2 Suspicious Website Logins	**1.2.A:** Identify common signs of a password attack.	Adversaries use common/stolen passwords and patterns to log in. Signs include many failed attempts, unusual login times, or unknown devices.	**Scenario 1B:** Detecting Unauthorized Logins. Students can analyze a Wi-Fi router authorization log to identify suspicious patterns, such as multiple failed attempts in a short duration or unknown devices.
	1.2.B: Explain how adversaries exploit weak authentication.	Users often use predictable patterns (names, dates, simple combinations). Adversaries use automated tools and gathered personal info to run dictionary attacks.	
	1.2.C: Explain how to make authentication stronger.	Use long, random, and unique passwords; employ password managers. Avoid personally meaningful words/numbers. Enable multifactor authentication (MFA) for an extra layer of proof.	
DAY 3 1.3 Best Practices for Public Networks	**1.3.A:** Identify the type of adversary (low- vs. high-skilled)	Adversaries range from low-skilled (using purchased tools) to high-skilled (creating tools and finding zero day vulnerabilities). Motivations include greed, recognition, politics, or specific causes.	**Scenario 1C:** Impacts of Using Public Wi-Fi Students can explain the hazards of fake captive portals and describe how to verify network authenticity before connecting to public Wi-Fi.
	1.3.B: Identify types of wireless attacks.	Evil twin attack: Setting up a malicious WAP with a similar name to a target network. Jamming attack: Flooding an area with EM signals to cause a denial of service (DoS). War driving: Detecting wireless beacons while moving around a target area.	
	1.3.C: Describe protection actions.	Consider data sensitivity (like DNS queries) before joining unencrypted networks. Verify that the network name matches the intended network exactly. Use a virtual private network (VPN) to encrypt traffic to the provider's system.	
DAY 4 1.4 AI-Based Cybersecurity Attacks	**1.4.A:** Explain how adversaries use AI to augment attacks.	Creating digital avatars (voice/image) for impersonation. Generative AI (LLMs) creating native-sounding phishing messages in any language. Prompt injection to extract sensitive info from LLMs. Poisoning training sets with false information. AI-powered reconnaissance of social media/public data. AI-enhanced coding for malware or finding software vulnerabilities.	**Scenario 1D:** AI-Powered Cyberattacks Students can describe how to verify an individual's identity during a suspected scam call by establishing and using shared secrets.
	1.4.B: Explain how to	Establish shared secrets (secret words) with	

	protect against AI attacks.	family/friends to verify identity. Use MFA to block access even if voice authentication is bypassed. Avoid entering sensitive data into AI chatbots. Verify AI output with reputable, non-AI-based sources.	
<u>DAY 5</u> 1.5 Leveraging AI in Cyber Defense	**1.5.A:** Explain how defenders use AI to protect data and review code. **1.5.B:** Explain how AI enables faster threat detection through probabilistic calculations.	Recommending secure configurations for firewalls and access controls. Analyzing application code for vulnerabilities. Suggesting detection rules for automated systems. Humans cannot examine the millions of daily digital network events. AI sorts malicious activity from harmless events at scale. AI can alert personnel or take programmed corrective actions automatically. Enables rapid intervention to prevent infrastructure damage and data loss.	**Scenario 1E:** AI-Powered Cyber Defense. Students can analyze the role of human oversight in AI-driven security, explaining why security technicians must review AI-generated code fixes or detector rules.

Unit Title:

Unit 2: Securing Spaces

Relevant Standards:

Skill 2: Mitigate Risk - Implement protective and deterrent security controls.

2.A Identify security controls, and explain how they mitigate risks.

2.B Determine layered security controls that address vulnerabilities.

Skill 3: Detect Attacks - Implement detection methods, monitor systems, and analyze evidence.

3.A Identify methods for monitoring systems, and explain how they detect attacks.

3.B Determine strategies and methods to detect attacks.

Skill 4: Collaborate - Work with others and AI to accomplish a task.

4.A Develop clear, shared team objectives related to a cybersecurity task.

4.B Determine clear roles and responsibilities for members of a team working to accomplish a cybersecurity task.

4.C Implement AI as a collaboration tool individually and as a group.

4.D Complete assigned work to accomplish a collaborative cybersecurity task.

Essential Question(s):	**Enduring Understanding(s):**
• Why is physical security considered a critical first layer of defense in a defense-in-depth cybersecurity strategy? • How do adversaries leverage a combination of social engineering and physical tactics to bypass security measures and gain unauthorized access? • In what ways can an organization evaluate, document, and prioritize the risks posed by various physical vulnerabilities? • What are the different strategies for managing physical risk (avoidance, transference, mitigation, and acceptance), and how do organizations determine which are most appropriate? • How do physical, technical, and managerial controls work together to create a resilient, layered defense for an organization's assets? • How can monitoring equipment and personnel be effectively placed and utilized to detect physical security breaches? • How do the different types of adversaries (e.g., script kiddies vs. hacktivists) and their motivations influence the physical threats an organization must defend against?	• Securing physical spaces is a critical first layer of defense in a comprehensive security strategy. If an adversary gains physical access to a device, they can often bypass technical controls that protect the system and its data. • A defense-in-depth (layered defense) strategy is essential because it provides resilience. By using multiple types of security controls (physical, technical, and managerial), an organization ensures that if one control is bypassed, another may still prevent or limit damage. • Absolute security is unattainable. Organizations must focus on risk management, which involves identifying and mitigating vulnerabilities while ultimately accepting a level of residual risk. • Risk is not a vague concept but a calculable combination of the likelihood of an attack and the severity of the potential damage. Once assessed, risks are managed through one of four primary strategies: avoidance, transference, mitigation, or acceptance. • Effective security requires adversarial thinking, which involves identifying vulnerabilities and attack methods to determine the best selection and placement of protective and detective controls. • Physical security is not just about locks and fences; it also involves protecting against social engineering tactics like piggybacking and tailgating, where adversaries manipulate authorized individuals to gain access.
Demonstration of Learning:	**Pacing for Unit**
Authentic unit scenarios designed to connect cybersecurity concepts to real-world personal security situations (see Lesson Sequence). Formal demonstration of learning is measured through multiple-choice questions on the AP Exam. Cumulative learning is measured through multiple-choice questions on the AP Exam, which weigh Skill Category 1 (Analyze Risk), Skill Category 2 (Mitigate Risk), and Skill Category 3 (Detect Attacks) equally at 25–40% each across the entire course content.	11 Block Periods • Topic 2.1: Cyber Foundations: ~ 4 Blocks • Topic 2.2: Physical Vulnerabilities and Attacks: ~ 3 Blocks • Topic 2.3: Protecting Physical Spaces: ~ 2 Blocks • Topic 2.4: Detecting Physical Attacks: ~ 2 Blocks
Family Overview (link below)	**Integration of Technology:**

AP Cybersecurity Family Overview	• Cameras and Visual Recording • Integrated Sensing • Biometric and Recognition Software • Entry Logs and Sensors • Hardware and Physical Access Controls • Access Control Systems • Port Security • Power Resilience • AI-Supported Analysis
Unit-specific Vocabulary:	**Aligned Unit Materials, Resources, and Technology (beyond core resources):**
• Pretexting • authority • intimidation • consensus • scarcity • familiarity • urgency • script kiddies • hacktivists • insider threats (insider adversaries) • cyberterrorists • transnational criminal organizations • reconnaissance • initial access • persistence • lateral movement • taking action • evading detection • open source intelligence (OSINT) • command and control (C2) protocol • remote access trojan (RAT) • rootkit • asset • likelihood • severity • vulnerability • avoidance • transference • mitigation • acceptance • residual risk • confidentiality • integrity • physical controls • technical controls • managerial controls • preventative controls • detective controls • corrective controls • defense-in-depth • piggybacking • tailgating • shoulder surfing • dumpster diving • card cloning • bollards • fencing	N/A

• access control vestibules • turnstiles • card readers • uninterruptible power supply (UPS) • power generators • security awareness training • workstation security policy • clean desk policy • motion sensors • stationary vs. patrolling security guards • facial recognition software • audit and evidence	
Opportunities for Interdisciplinary Connections:	**Anticipated misconceptions:**
• Psychology and Behavioral Science: The study of social engineering (Topic 2.1) is deeply rooted in psychology. Students analyze how adversaries use specific psychological tactics to manipulate human behavior. This connects to behavioral science concepts of how humans respond to pressure, fear, and social norms. • Sociology and Political Science: The classification of adversaries (Topic 2.1) connects to sociology and political science by examining the motivations behind attacks. Students study hacktivists motivated by social or political causes and cyberterrorists who seek to disrupt civil infrastructure, such as power grids, to impact entire regions or nations. This encourages an understanding of how external social and political beliefs can manifest as technical threats. • Cost-Benefit Analysis: Students must determine "cost-effective" solutions, where the price of a security control is weighed against the expected financial loss from an attack. • Risk Management Strategies: Concepts like risk transference (e.g., using insurance) and risk acceptance are standard business operations used to handle organizational uncertainty. • Impact Assessment: Students evaluate the severity of damage not just in technical terms, but also through financial, operational, and reputational costs. • Architecture: Students engage in workplace-style tasks like reviewing building plans to identify vulnerabilities and strategically placing physical barriers such as bollards, fencing, and access control vestibules. • Physical Engineering: Students study the engineering of power resilience through Uninterruptible Power Supplies (UPS) and generators. • Law and Ethics: The course requires the integration of legal and professional norms throughout all units. In Unit 2, this connects to Civics and Law as students learn about regulations like the Privacy Act of 1974, HIPAA, and industry-specific rules like PCI DSS. They	• Over-Reliance on Technical Controls • The Pursuit of "Absolute Security" • Limiting Social Engineering to the Digital Realm • "More is Better" in Detection Technology • Conflating Security Control Functions • Motivation vs. Skill of Adversaries

also consider the broader impact of cybersecurity on societies and governments.	
Connections to Prior Units:	**Connections to Future Units:**
• Application of Risk Management Principles: Students in Unit 2 practice selecting security controls based on the principles introduced in Unit 1. While Unit 1 focuses on identifying vulnerabilities and mitigating risks at a personal level, Unit 2 applies these skills to physical organizational assets, such as securing a research lab. • Continuity of Social Engineering Tactics: Unit 1 and 2 place heavy emphasis on the human element of security. Unit 1 introduces how adversaries use psychological triggers like urgency and intimidation to influence behavior through digital means like phishing. Unit 2 expands this by showing that social engineering is also a primary tool for conducting physical attacks. Students learn how tactics like familiarity and consensus are used in person to facilitate breaches like piggybacking. • Evolution of Detection and Log Analysis: The skill of detecting attacks through indicators of compromise (IoCs) is a major thread. In Unit 1, students learn to identify signs of suspicious activity—such as many failed login attempts—by analyzing digital log files. In Unit 2, this skill is applied to physical entry logs. Students analyze how long electronic doors remain open to detect patterns that signify tailgating or unauthorized access. • Adversary Classification: Unit 2 provides more granular detail on the types of adversaries first mentioned in Unit 1. Unit 1 establishes the baseline classification of adversaries by skill level (low-skilled vs. high-skilled). Unit 2 builds on this by identifying specific groups, such as script kiddies, hacktivists, and insider threats, and exploring their unique motivations and methods. • Ongoing Role of Artificial Intelligence (AI): The course-wide theme of leveraging AI-powered tools continues. Just as students in Unit 1 see how defenders use AI for code review and threat detection, students in Unit 2 are expected to use AI to support risk assessment and identify physical vulnerabilities.	Building the Defense-in-Depth Strategy: Unit 2 introduces the concept of defense-in-depth (layered defense), where students learn that physical security is necessary because gaining physical access often allows an adversary to bypass many technical controls. Future units add subsequent layers to this model: • Unit 3 adds the network layer (firewalls, segmentation). • Unit 4 adds the device layer (antimalware, host-based firewalls). • Unit 5 adds the application and data layer (encryption, access controls). Evolution of Risk Assessment: The formal risk assessment process taught in Topic 2.1 is the exact framework students apply to different domains in every future unit: • In Unit 3, students assess risk from network vulnerabilities. • In Unit 4, they evaluate risks from device-specific vulnerabilities. • In Unit 5, they analyze risks to sensitive applications and files. Progression of Log Analysis and Detection: Unit 2 establishes the skill of detecting attacks by analyzing logs (specifically physical entry logs). This skill matures through the following units: • Unit 3: Students analyze network traffic logs and packet captures to find indicators of compromise (IoCs) like ARP poisoning or smurf attacks. • Unit 4: Students review authentication logs for signs of password attacks like spraying or credential stuffing. • Unit 5: Students examine web application and server logs for injection-type attacks like SQLi or directory traversals. Physical Access vs. Technical Port Security: Unit 2 introduces the vulnerability of exposed device ports in physical spaces. This connects directly to future technical mitigations: • Unit 3 explores port security on switches to prevent adversaries from plugging in rogue access points. • Unit 4 teaches students how to configure BIOS/UEFI protection to prevent adversaries from booting into unauthorized modes if they have physical access to a device. Protection of Data at Rest: Unit 2 emphasizes protecting the physical environment where data is stored (e.g., locking server rooms). Unit 5 connects this to the states of data, specifically data at rest, noting that it is critical to protect the physical drive from theft or destruction before even applying digital encryption.

Differentiation through *Universal Design for Learning*

	Engagement	Representation	Action & Expression
2.1A	Physical security escape-room puzzle focusing on tailgating and baiting.	Visual matrix categorizing tailgating, impersonation, and dumpster diving.	Build a physical security assessment rubric or design front-desk safety training slides.
2.1B	Case study analysis comparing malicious insiders vs. external physical intruders.	Venn diagram illustrating motives, access levels, and capabilities of physical adversaries.	Produce a physical threat actor infographic or write an insider threat risk profile.

2.1C	Cyber Kill Chain mapping activity tracking a breach from recon to exfiltration.	Sequential visual timeline mapping the 7 Cyber Kill Chain stages.	Construct a breach timeline storyboard or present a historic cyberattack case study.
2.1D	Facility inspection activity evaluating vulnerabilities in a physical classroom/lab.	Flowchart illustrating Risk = Asset x Threat x Vulnerability.	Draft a facility Risk Assessment Report or create an interactive risk evaluation matrix.
2.1E	"Risk Budgeting" simulation deciding to Accept, Avoid, Mitigate, or Transfer risks.	2x2 Risk Decision Matrix (Impact vs. Likelihood) mapped to management strategies.	Present a business pitch justifying risk management choices or write a policy proposal.
2.1F	Hands-on sorting game classifying Physical, Technical, and Managerial controls.	Multi-tier grid categorizing controls by type and function (Deterrent, Preventative, Detective).	Create a security control index poster or code a review quiz application.
2.1G	"Swiss Cheese Model" physical demonstration showing layered defense overlap.	Concentric circle diagram showing physical, network, host, and data defenses.	Build a 3D/digital model of layered defenses or present a Defense-in-Depth plan.
2.2A	Virtual walk-through audit of server rooms spotting physical security flaws.	Taxonomy chart detailing physical attack vectors (lock picking, rogue drop boxes).	Conduct a physical facility audit report supported by photos or video clips.
2.2B	Scenario simulation analyzing cascading failures from physical disruptions.	Cause-and-effect (Fishbone) diagram linking physical gaps to asset destruction.	Write a physical vulnerability failure report or record a brief security briefing.
2.2C	Physical penetration tester role-play evaluating facility access points.	Standardized physical security assessment checklist with risk rating scales.	Deliver a formal Physical Security Audit Document with weighted risk scores.
2.3A	Review corporate visitor logs and badge policy documents.	Visual policy hierarchy detailing visitor escorting, badging, and clean-desk policies.	Draft a Physical Security Standard Operating Procedure (SOP) manual.
2.3B	"Facility Redesign" challenge modifying physical layouts to enhance security.	Before-and-after floorplan blueprints incorporating mantraps, bollards, and locks.	Present an architectural security proposal or design an interactive floorplan.
2.4A	Hands-on inspection of motion detectors, glass-break sensors, and CCTV analytics.	Hardware diagram mapping infrared, acoustic, and magnetic sensors to zones.	Record a video demonstration or write a technical buyer's guide for detection hardware.
2.4B	"Blind Spot Elimination" game placing virtual sensors for optimal coverage.	Heatmap visual overlay on floorplans showing sensor ranges and blind spots.	Present a sensor placement architectural diagram supported by technical justifications.
2.4C	Investigate physical security logs and badge reader timestamp discrepancies.	Event timeline correlating badge access logs with physical CCTV footage.	Write an incident forensic report or present a timeline analysis slide deck.

Supporting Multilingual/English Learners (*CELP standards*)

	Emerging	Expanding	Bridging
2.1A	Categorize scenario flashcards into attack types (e.g., *phishing, vishing, tailgating, shoulder surfing*).	Write brief scenario descriptions identifying social engineering attack types with supporting clues.	Analyze complex physical and digital social engineering scenarios to identify underlying attack vectors.
2.1B	Match threat actor names (e.g., *insider, nation-state, hacktivist*) to primary motive keywords and images.	Describe adversary motivations and capabilities using comparative graphic organizers.	Profile threat actors in real-world case studies and detail their tactical tendencies and resource levels.
2.1C	Sequence visual cards representing the Cyber Kill Chain / attack lifecycle (e.g., *Recon, Access, Execution*).	Describe each phase of a cyberattack using sequential transition words (*initially, subsequently, ultimately*).	Map complex multi-stage real-world attacks across standard frameworks (e.g., MITRE ATT&CK, Cyber Kill Chain).
2.1D	Complete a visual Risk Matrix (Asset, Threat, Vulnerability) using color-coded cards (High, Medium, Low).	Explain the risk assessment steps using paragraph frames and formulas.	Conduct a quantitative and qualitative risk assessment for a given scenario and articulate findings in a formal report.
2.1E	Sort risk responses into four bins: *Accept, Avoid, Mitigate, Transfer* using scenario prompts.	Explain choices for risk management strategies using conditional frames ("*If the risk is too costly, the organization should transfer it by...*").	Justify optimal risk management decisions based on cost-benefit analysis and business continuity requirements.

2.1F	Classify controls into categories (*Technical, Operational, Physical*) using a picture-supported sorting mat.	Describe the functions of control categories (*Preventative, Detective, Corrective*) using targeted technical vocabulary.	Evaluate existing security controls within an enterprise architecture and identify missing control types.
2.1G	Label the layers of the "Swiss Cheese" or defense-in-depth model on a graphic diagram.	Explain defense-in-depth using analogy frames ("*Defense-in-depth is like a castle because...*").	Formulate a technical defense-in-depth architecture plan defending against single points of failure across an organization.
2.2A	Label physical threat illustrations (e.g., *tailgating, dumpster diving, badge cloning, lock picking*).	Write short descriptions of physical security breaches observed in provided case study diagrams.	Distinguish between subtle physical attack techniques and document physical breach indicators.
2.2B	Match physical vulnerabilities (e.g., *unlocked doors, unshredded paper*) to potential asset damage/loss.	Explain cause-and-effect relationships between physical vulnerabilities and business disruption using structured prompts.	Synthesize physical threat scenarios to project potential operational, financial, and physical impacts on assets.
2.2C	Complete a fill-in checklist rating physical vulnerabilities observed in a site floor plan image.	Draft structured risk assessment notes using a provided vulnerability-impact table template.	Conduct a comprehensive physical security audit and produce a standardized risk documentation matrix.
2.3A	Match physical security managerial terms (e.g., *visitor logs, clean desk policy, security training*) to pictures.	Explain the purpose of physical security policies using modal verbs ("*Employees must lock...*", "*Visitors should...*").	Draft clear, enforceable managerial control policies for physical access control and asset protection.
2.3B	Select appropriate physical mitigations (e.g., *mantrap, bollards, CCTV, badges*) from a visual choice board for given threats.	Explain selected physical mitigation strategies using justification sentence frames ("*We chose [control] in order to prevent [threat]*").	Develop a comprehensive physical security mitigation proposal tailored to high-risk facilities.
2.4A	Circle physical detection devices in a facility diagram (e.g., *motion sensors, CCTV, door contact sensors*).	Describe how specific physical security controls alert security personnel using sequential language.	Analyze physical detection control capabilities and evaluate their responsiveness to diverse attack vectors.
2.4B	Place physical security control icons on a building floor plan map at appropriate entry/exit points.	Justify placement of detection controls on a facility floor plan using spatial prepositions (*adjacent to, perimeter, bottleneck*).	Design an optimized physical sensor placement layout that minimizes blind spots and maximizes coverage.
2.4C	Match security sensor alert logs (e.g., "*Door 3 forced open*") to corresponding physical incidents.	Interpret physical security alert logs and describe the likely incident using structured reporting templates.	Correlate physical access control logs and video surveillance data to reconstruct physical security incidents.

Unit Outline

Lesson Sequence	Learning Target	Success Criteria	Assessment
DAY 1 -2 2.1 Part 1 Cyber Foundations	**2.1.A:** Identify social engineering attacks.	Adversaries use psychological tactics such as pretexting, authority, intimidation, consensus, scarcity, familiarity, and urgency to manipulate targets into a desired action.	**Defense in Depth**: Professional Skills/Collaboration Rubrics. Students can accurately classify adversaries (e.g., script kiddies vs. hacktivists) and explain psychological tactics like pretexting or consensus in a formative quiz. **Lesson Plans provided by AP Classroom.** Students create a visual model of a layered defense for an organization, documenting how physical, technical, and
	2.1.B: Identify types of adversaries.	Adversaries include script kiddies, hacktivists, insider threats, cyberterrorists, and transnational criminal organizations, each with distinct motivations ranging from greed to political beliefs.	
DAY 3 -4 2.1 Part 2 Cyber Foundations	**2.1.C:** Describe the phases of a cyberattack.	The typical phases are reconnaissance, initial access, persistence, lateral movement, taking action, and evading detection.	
	2.1.D: Describe the risk assessment process.	Risk assessment evaluates the likelihood and severity of an attack against a specific vulnerability for an	

		asset.	managerial controls work together.
	2.1.E: Identify strategies for managing risk.	Organizations manage risk through avoidance, transference, mitigation, and acceptance.	
	2.1.F: Identify types of security controls.	Controls address confidentiality, integrity, or availability (CIA) and are classified by type (physical, technical, managerial) and function (preventative, detective, corrective).	
	2.1.G: Explain why a defense-in-depth security strategy is necessary to optimally protect an organization.	Defense-in-depth (layered defense) provides resilience so that if one control is bypassed, another may still prevent or limit damage.	
DAY 5 -7 2.2 Physical Vulnerabilities and Attacks	**2.2.A:** Identify common physical attacks.	Common attacks include piggybacking, tailgating, shoulder surfing, dumpster diving, and card cloning.	**Scenario 2A (Xtensr Labs)**: Building and physical plans; AI-powered tools for risk documentation. **Scenario 2A Part 1:** Students review building plans for Xtensr Labs to identify vulnerabilities and document the likelihood and severity of potential attacks.
	2.2.B: Explain how threats can exploit common physical vulnerabilities to cause loss, damage, disruption, or destruction to assets.	Physical access can allow adversaries to disrupt power, steal information, or install malware via open device ports.	
	2.2.C: Assess and document risks from physical vulnerabilities.	Risks range from high (unrestricted access to sensitive systems) to low (unsecured low-value assets).	
DAY 8 -9 2.3 Protecting Physical Spaces	**2.3.A:** Identify managerial controls related to physical security.	Controls include security awareness training and a workstation security policy (e.g., clean desk policies, privacy screens).	**CED Topic 2.3**; Examples of Workstation Security and Clean Desk policies. **Scenario 2A Part 2:** Students recommend specific mitigations (e.g., bollards, access control vestibules) and draft a Workstation Security Policy.
	2.3.B: Determine mitigation strategies for risks from physical vulnerabilities.	Mitigations include physical barriers (fencing, bollards), locks, card readers, access control vestibules, and uninterruptible power supplies (UPS).	
DAY 10-11 2.4 Detecting Physical Attacks	**2.4.A:** Identify ways security controls can detect physical attacks.	Detection methods include cameras, security guards, motion sensors, and alert employees.	**Entry Logs**: Motion sensor and camera placement diagrams; AI for threat detection. Students analyze entry logs to detect "indicators of compromise" like tailgating and propose camera/sensor placement to minimize false alarms.
	2.4.B: Determine effective placement of security controls for detecting physical attacks.	Controls should be placed at points of ingress/egress and areas where traffic is unexpected, like server rooms.	
	2.4.C: Apply detection techniques to identify physical attacks.	Techniques include using facial recognition, pairing motion detectors with cameras, and reviewing entry logs for signs of piggybacking or tailgating.	

Unit Title:

Unit 3: Securing Networks

Relevant Standards:

Skill 1: Analyze Risk - Evaluate risk to organizational assets.

1.C Evaluate, with and without the support of AI, the likelihood and impact of risks.

1.D Document, with and without the support of AI, the likelihood and impact of risks.

Skill 2: Mitigate Risk - Implement protective and deterrent security controls.

2.A Identify security controls, and explain how they mitigate risks.

2.C Evaluate, with and without the support of AI, the impact of protective risk-management strategies.

2.D Implement and log mitigations with and without the support of AI.

Skill 3: Detect Attacks - Implement detection methods, monitor systems, and analyze evidence.

3.C Evaluate the impact of threat detection methods.

Skill 4: Collaborate - Work with others and AI to accomplish a task.

4.A Develop clear, shared team objectives related to a cybersecurity task.

4.B Determine clear roles and responsibilities for members of a team working to accomplish a cybersecurity task.

4.C Implement AI as a collaboration tool individually and as a group.

4.D Complete assigned work to accomplish a collaborative cybersecurity task.

Essential Question(s):	**Enduring Understanding(s):**
• How does the transmission of data between devices create new opportunities for adversaries, and how can defenders protect data while it is in transit? • What are common network-based attacks (such as ARP poisoning, DNS poisoning, and Smurf attacks), and how do they exploit specific network vulnerabilities? • Why is network segmentation (using subnets, VLANs, and DMZs) a critical strategy for isolating traffic and preventing an adversary's lateral movement? • How do firewalls use Access Control Lists (ACLs) to manage the flow of traffic, and why is their strategic placement and rule precedence vital for network security? • In what ways do automated security tools, such as NIDS, NIPS, and SIEM, allow organizations to monitor systems and detect malicious activity more effectively? • How can organizations leverage Artificial Intelligence (AI) and probabilistic models to manage massive amounts of network data and enable faster threat detection? • What are the trade-offs between different detection methods (signature-based, anomaly-based, and hybrid) regarding speed, cost, and human factors like alert fatigue?	• The transmission of data between devices through a computer network creates significant opportunities for adversaries. • Dividing a network into smaller, isolated segments (subnets or VLANs) is a critical defensive strategy. It isolates network traffic, which can prevent a security breach on one subnet from impacting devices on other subnets and limits an adversary's ability to move laterally across the network. • Effective network security requires the strategic deployment of multiple technical controls, including firewalls to manage traffic flow and wireless encryption (such as WPA3) to ensure data confidentiality. • Firewalls use Access Control Lists (ACLs) to permit or deny traffic based on specific criteria like IP addresses and ports. Because these rules are executed in a specific precedence order, the sequence in which they are written directly determines the network's security posture. • While humans cannot analyze the millions of digital events occurring daily, automated tools and Artificial Intelligence (AI) can quickly sort and classify data patterns to identify malicious activity. • Organizations must choose between signature-based (efficient for known threats) and anomaly-based (better for novel attacks) detection. These choices involve balancing factors such as false positive rates, which can lead to alert fatigue, and false negative rates, which allow adversaries to bypass detection.
Demonstration of Learning:	**Pacing for Unit**
Authentic unit scenarios designed to connect cybersecurity concepts to real-world personal security situations (see Lesson Sequence). Formal demonstration of learning is measured through multiple-choice questions on the AP Exam. Cumulative learning is measured through multiple-choice questions on the AP Exam, which weigh Skill Category 1 (Analyze Risk), Skill Category 2	14 Block Periods • Topic 3.1: Network Vulnerabilities and Attacks: ~ 3 Blocks • Topic 3.2: Protecting Networks: Managerial Controls and Wireless Security: ~ 2 Blocks • Topic 3.3: Protecting Networks: Segmentation: ~ 1 Block • Topic 3.4: Protecting Networks: Firewalls: ~ 4 Blocks • Topic 3.5: Detecting Network Attacks: ~ 4 Blocks

(Mitigate Risk), and Skill Category 3 (Detect Attacks) equally at 25–40% each across the entire course content.	
Family Overview (link below)	**Integration of Technology:**
AP Cybersecurity Family Overview	• Firewall Configuration • Segmentation Tools • Secure Architectures • Automated Monitoring and Detection Systems • Network Intrusion Detection Systems (NIDS) and Network Intrusion Prevention Systems (NIPS) • Log Aggregation (SIEM): Security Information and Event Management • Vulnerability Scanning • Virtual Private Networks (VPNs).
Unit-specific Vocabulary:	**Aligned Unit Materials, Resources, and Technology (beyond core resources):**
• On-path Attack (Man-in-the-Middle) • ARP Poisoning • MAC Spoofing • MAC Flooding • DNS Poisoning • Smurf Attack • Distributed Denial of Service (DDoS) • Jamming Attack • Network Segmentation • Subnetting • VLAN (Virtual Local Area Network) • Screened Subnet (DMZ) • Port Security • Access Control List (ACL) • Rule Precedence • Stateless Firewall • Stateful Firewall (Dynamic Packet Filtering) • Next-Generation Firewall (NGFW) • VPN (Virtual Private Network) • WPA3 • Beacon Frame • NIDS / NIPS • SIEM (Security Information and Event Management) • Signature-Based Detection • Anomaly-Based Detection • False Positive / False Negative • Alert Fatigue • Probabilistic Calculations	N/A
Opportunities for Interdisciplinary Connections:	**Anticipated misconceptions:**
• Healthcare Law: Scenario 3A (Protecting Patient Medical Data) requires students to secure internal file servers containing patient records. This connects to the Health Insurance Portability and Accountability Act (HIPAA), which regulates the protection of health information (PHI). • Military and National Security: Scenario 3C places students in the role of a technician on a naval submarine, managing secure networks for weapons systems and operations. This provides a	• The "More is Better" Fallacy in Detection • Order Irrelevance in Firewall Rules • Conflating Detection (NIDS) with Prevention (NIPS) • Overestimating AI's Certainty • Misunderstanding the Limits of Signature-Based Detection • Confusing Network Segmentation with Physical Separation

window into the ethics and protocols of national defense and military-grade cybersecurity. • Probability and Statistics: Students study how Artificial Intelligence (AI) algorithms use probabilistic calculations to report a percentage likelihood that a specific activity pattern is malicious. • Quantitative Analysis: Students must evaluate the trade-offs of detection methods based on statistical rates of false positives and false negatives, which determine the effectiveness of a system and the risk of alert fatigue. • Electromagnetics: Students learn to detect jamming attacks by scanning for electromagnetic (EM) noise within the wireless frequency range. • Geometry and Signal Analysis: The curriculum mentions using signal triangulation to locate and disable unauthorized wireless access points (evil twins). • Financial Regulations: Protecting networks that handle transactions connects to the Payment Card Industry Data Security Standard (PCI DSS). • Resource Management: Students evaluate the impact of SIEM systems that aggregate logs from multiple sources to detect broad patterns, mirroring business intelligence and operational oversight tasks. • Economic Evaluation: The unit requires students to evaluate security controls based on cost versus speed of detection, ensuring that the chosen tools fit within an organization's budget. • Public Service and Emergency Management: Scenario 3B connects cybersecurity to disaster relief. Students must set up a secure wireless network at an emergency shelter following a natural disaster to provide internet access for displaced families. This demonstrates how cybersecurity is a foundational component of modern civil service and crisis management.	
Connections to Prior Units:	**Connections to Future Units:**
• Progression of the Defense-in-Depth Model: Unit 3 adds a critical layer to the defense-in-depth (layered defense) strategy introduced in Unit 2. While Unit 2 focuses on the physical perimeter (locks, cameras, guards) as the first layer of defense, Unit 3 transitions to the network layer, teaching students how to protect devices once they are connected and communicating. • Application of the Risk Assessment Framework: The formal risk assessment process defined in Unit 2 is the exact framework students apply to networking in Unit 3. In this unit, students move from assessing physical risks (like an unlocked door) to technical network risks (like an improperly configured firewall). • Evolution of Log Analysis and Detection: The practice of identifying indicators of compromise	Progression of the Defense-in-Depth Strategy: Unit 3 focuses on the network layer of defense. This connects directly to: • Unit 4 (Device Layer): Students learn that while Unit 3 firewalls protect the network perimeter, devices require their own security because adversaries who bypass network controls (or operate from within the network) must be stopped at the host level. • Unit 5 (Application/Data Layer): This represents the final and most critical layer. Unit 3 teaches how to protect data in transit across the network, while Unit 5 focuses on protecting that same data at rest and in use. Evolution of Firewall Logic: The technical logic of filtering traffic introduced in Unit 3 is directly applied in Unit 4: • In Unit 3, students master network-based firewalls, using Access Control Lists (ACLs) and rule precedence to manage traffic flow between network segments. • In Unit 4, students apply these exact same principles—ACLs, rule order, and permitting/denying by IP and port—to configure host-based firewalls that protect individual devices.

(IoCs) through log analysis is a continuous thread throughout the course:
    - Unit 1: Students analyze digital logs for unauthorized website logins.
    - Unit 2: Students analyze physical entry logs to detect tailgating or piggybacking.
    - Unit 3: Students refine these skills by analyzing network log files and packet captures to identify technical attacks like ARP poisoning or Smurf attacks.
- Adversary Tactics and Phases: The types of adversaries (e.g., script kiddies, hacktivists) and the phases of a cyberattack (reconnaissance, initial access, lateral movement, etc.) introduced in Unit 2 provide the context for the network attacks studied in Unit 3. Unit 3 specifically explores how adversaries use network vulnerabilities to facilitate lateral movement, a concept first defined as a key phase of an attack in Unit 2.
- VPNs: Unit 1 introduces Virtual Private Networks (VPNs) as a personal tool to protect sensitive data on public Wi-Fi. Unit 3 expands this concept into a professional managerial control, where students learn to develop organizational VPN policies for secure remote access.
- Artificial Intelligence: The theme of leveraging AI in cyber defense started in Unit 1. Unit 3 provides a more technical explanation of how AI algorithms use probabilistic calculations to sort through the millions of digital events logged on networks daily, a task impossible for human teams alone.

Scaling Detection and Log Analysis: The skill of identifying Indicators of Compromise (IoCs) through digital evidence matures across the units:
- Unit 3 focuses on network-based IoCs found in traffic patterns, such as ARP poisoning or Smurf attacks.
- Unit 4 shifts to host-based IoCs, where students analyze authentication logs for signs of credential stuffing or password spraying.
- Unit 5 culminates in application-based IoCs, such as detecting SQL injection or XSS signatures within web application and server logs.

From Network Encryption to Data Cryptography: Unit 3 introduces encryption as a tool for securing communication channels, which is expanded in Unit 5:
- Unit 3 focuses on protocol-specific encryption, such as WPA3 for wireless networks and VPNs for remote access.
- Unit 5 dives into the mathematical foundations of cryptography (symmetric vs. asymmetric algorithms), teaching students the underlying mechanics that make the network-level encryption they used in Unit 3 possible.

Mitigating Lateral Movement: A central theme of Unit 3 is network segmentation (using VLANs, subnets, and DMZs) to prevent an adversary's lateral movement.
- This connects to Unit 4 and Unit 5, which explore the consequences of failed segmentation. In these units, students see how an adversary who successfully moves laterally can exploit device vulnerabilities (Unit 4) to ultimately reach their end goal: stealing or destroying sensitive data (Unit 5).

Consistent Application of Risk Assessment: The risk assessment framework (identifying assets, vulnerabilities, threats, likelihood, and impact) practiced in Unit 3 is the standard methodology students will use for the remainder of the course.
- In Unit 4, they apply it to IoT and smart devices.
- In Unit 5, they apply it to proprietary data and web applications.

Differentiation through *Universal Design for Learning*

	Engagement	Representation	Action & Expression
3.1A	Packet inspection activity identifying MitM, DDoS, and ARP spoofing patterns.	Visual diagrams illustrating packet manipulation during network attacks.	Create a network attack cheat sheet or record a packet capture (Pcap) analysis.
3.1B	Lab simulation of unencrypted HTTP traffic sniffing using Wireshark.	Side-by-side packet flow diagrams comparing plaintext vs. TLS encrypted traffic.	Write a network exploit report or give a technical walk-through of packet interception.
3.1C	Network scanning challenge using Nmap in a sandbox to discover open ports.	Risk matrix mapping open ports and unpatched services to exploit severity.	Compile an Nmap vulnerability scan report with documented risk scores.
3.2A	Debate session on network Acceptable Use Policies (AUP) and access rules.	Organizational hierarchy chart linking network governance to policy enforcement.	Draft an Acceptable Use Policy (AUP) document or record a policy video.
3.2B	Sandbox lab configuring router settings (WPA3, SSID hiding, MAC filtering).	Step-by-step visual screenshot guide for wireless router security hardening.	Produce a router security tutorial video or submit a lab configuration portfolio.
3.3A	Design a network topology for a company balancing guest, employee, and server traffic.	Network architecture diagram showing VLANs, subnets, and micro-segmentation.	Build a topology in Cisco Packet Tracer or construct a physical network diagram.
3.3B	Simulation comparing blast radius of malware on flat vs. segmented networks.	Comparative animation showing lateral movement restrictions within VLANs.	Write an executive memo advocating network segmentation or deliver a presentation.

3.4A	Feature-matching game comparing packet-filtering, stateful, and Next-Gen Firewalls.	Feature table mapping OSI layers (Layer 3/4 vs. Layer 7) to firewall types.	Create a firewall decision guide infographic or record an explanatory mini-lecture.
3.4B	"Firewall Bouncer" activity filtering incoming packets based on ACL rule sets.	Color-coded ACL table displaying Source/Destination IP, Port, Protocol, Action.	Write an ACL rule set for a business scenario or record a rule evaluation video.
3.4C	Virtual lab placing firewalls in DMZ and internal positions to block traffic.	Network architectural diagram highlighting DMZ positioning and firewall placement.	Submit a firewall configuration file or present a firewall placement diagram.
3.5A	Inspection of Intrusion Detection (IDS) vs. Intrusion Prevention Systems (IPS) alerts.	Workflow chart contrasting passive monitoring (IDS) vs. active blocking (IPS).	Create an IDS/IPS comparison chart or produce an explanatory video.
3.5B	Case study on AI SIEM tools detecting automated network anomalies.	Infographic tracing AI SIEM data ingestion, event correlation, and automated isolation.	Write a research summary or present a proposal on AI threat detection adoption.
3.5C	Scenario challenge selecting between signature, heuristic, or behavioral detection.	Decision tree graphic guiding selection of detection methods based on threat types.	Draft a network defense strategy paper justifying selected detection methods.
3.5D	Analysis of false positives vs. false negatives and impact on SOC team fatigue.	Trade-off spectrum chart balancing detection sensitivity with network performance.	Draft a detection impact evaluation report or present a cost-benefit analysis.
3.5E	"Log Forensics Detective" activity analyzing firewall/server logs for indicators of compromise.	Highlighted log file cheat sheet with key fields (Timestamp, Source IP, Event Code).	Write an incident forensic report or present a web log analysis walkthrough.

Supporting Multilingual/English Learners (*CELP standards*)

	Emerging	Expanding	Bridging
3.1A	Match network attack names (e.g., *DoS/DDoS, Man-in-the-Middle, Spoofing*) to simple network diagrams.	Write definitions of network attacks using provided technical vocabulary and key phrase starters.	Categorize and contrast advanced network attack vectors based on OSI model layers and execution mechanisms.
3.1B	Fill in diagram callouts showing how an attacker intercepts or floods unencrypted network traffic.	Explain network vulnerability exploitation using step-by-step cause-and-effect frames.	Analyze network topology diagrams to identify exploited protocol weaknesses (e.g., unencrypted HTTP, ARP poisoning).
3.1C	Complete a guided risk matrix for network assets (e.g., *unpatched router, open ports*).	Write network risk statements using the format: "*The network is vulnerable to [threat] because of [vulnerability], leading to [impact]*".	Formulate comprehensive network risk assessment documentation including likelihood, impact, and risk scores.
3.2A	Match network security policies (e.g., *Acceptable Use Policy, Password Policy*) to illustrative rule cards.	Describe the objective of network security managerial controls using imperative and regulatory language.	Author operational network security policies that align with industry frameworks (e.g., NIST SP 800-53).
3.2B	Follow a step-by-step visual screenshot guide to select *WPA3* encryption and change default SSIDs on a router GUI.	Complete wireless security configuration tasks and explain chosen settings (*WPA3, disabled WPS*) using short notes.	Independently configure enterprise-grade wireless security parameters and document security posture choices.
3.3A	Color-code different network zones (e.g., *DMZ, Internal, Guest, IoT*) on a network architecture diagram.	Describe network segmentation techniques (e.g., *VLANs, Subnetting, Firewalls*) using descriptive paragraphs.	Design network segmentation schemes using subnets, VLANs, and micro-segmentation principles.
3.3B	Select visual choices demonstrating how a firewall/VLAN blocks lateral movement during a breach.	Explain how segmentation stops lateral movement using contrast frames ("*Without segmentation... However, with segmentation...*").	Evaluate network architecture designs and justify segmentation strategies to prevent breach propagation.
3.4A	Match firewall types (e.g., *Stateless, Stateful, Next-Gen/NGFW*) to feature summaries using graphic cards.	Describe differences between stateless, stateful, and application-level firewalls using comparative tables.	Analyze enterprise requirements to select and justify the deployment of specific firewall types.

3.4B	Circle *ALLOW* or *DENY* actions on sample firewall ACL rules based on source/destination IP matching prompts.	Explain how ACL rule order (*top-down processing*) affects firewall traffic filtering using conditional statements (*"If traffic matches rule 1..."*).	Write, critique, and optimize sequential firewall ACL rules to enforce least privilege access.
3.4C	Place firewall icons between network zones on a diagram and match pre-written rule blocks to interfaces.	Justify firewall placement at network boundaries and complete rule configuration exercises using guided templates.	Architect firewall network placement (e.g., dual-homed DMZ) and configure complex filtering rulesets.
3.5A	Label automated tools (e.g., *IDS, IPS, SIEM, Packet Sniffer*) on a network monitoring graphic.	Describe the function of automated network detection tools using targeted verbs (*monitors, alerts, blocks, logs*).	Compare passive detection (IDS) vs. active prevention (IPS) tools in enterprise network monitoring.
3.5B	Match AI detection features (e.g., *anomaly detection, automated threat isolation*) to visual scenario pairs.	Write short explanations describing how AI processes large log volumes to identify abnormal network traffic patterns.	Analyze the integration of AI-driven Threat Intelligence and SOAR (Security Orchestration, Automation, and Response) platforms.
3.5C	Select the appropriate detection method (e.g., *signature-based vs. anomaly-based*) using a simple decision flowchart.	Recommend signature-based or anomaly-based detection for specific scenarios using conditional sentence starters.	Justify the selection and integration of hybrid detection methodologies for complex network environments.
3.5D	Categorize detection results into a 2×2 grid (*True Positive, False Positive, True Negative, False Negative*).	Explain the operational impacts of *False Positives* vs. *False Negatives* on security teams using structured sentence frames.	Evaluate IDS/IPS performance metrics (precision, recall, alert fatigue) and recommend tuning adjustments.
3.5E	Highlight malicious indicators (e.g., *unusual port, repeated failed handshakes*) in simplified, highlighted network log samples.	Analyze Wireshark packet summaries or Syslog entries to identify attack signatures and document findings in writing frames.	Perform deep packet analysis and log evaluation to reconstruct network attack timelines and scope.

Unit Outline

Lesson Sequence	Learning Target	Success Criteria	Assessment
DAYS 1-3 3.1 Network Vulnerabilities & Attacks	**3.1.A:** Identify common network attacks.	Attacks include ARP poisoning (MAC spoofing), MAC flooding (eavesdropping/sniffing), DNS poisoning (credential harvesting), and Smurf attacks (DoS/DDoS).	**Scenario 3A:** Protecting Patient Medical Data. Students can identify and explain technical attacks such as ARP poisoning, DNS poisoning, and Smurf attacks. Students assess risk for Scenario 3A by identifying vulnerabilities in existing architecture.
	3.1.B: Explain exploitation of network vulnerabilities.	Vulnerabilities include improperly configured firewalls, open data ports, rogue access points, and unauthenticated networks.	
	3.1.C: Assess and document network risks.	Defenders use automated vulnerability scanners to evaluate risk levels (low, moderate, high) based on technical difficulty and potential impact on confidentiality, integrity, or availability.	
DAY 4-5 3.2 Managerial Controls & Wireless Security	**3.2.A:** Identify managerial controls for network security.	Managerial controls involve establishing organizational standards for router security, switch security, VPN usage, and wireless security policies.	**Scenario 3B:** Configuring a Secure Wireless Network. Students describe security configurations for Scenario 3B, including disabling beacon frames, managing signal strength, and implementing WPA3 encryption.
	3.2.B: Configure wireless network security features.	Technical mitigations include disabling beacon frames, controlling signal strength, using WPA3 encryption, and enabling MAC filtering.	
DAY 6 3.3 Best	**3.3.A:** Identify techniques for segmenting a network.	Techniques include creating a screened subnet (DMZ), subnetting via IP addressing, and utilizing VLANs on switches.	**Scenario 3C:** Protecting a Network on a Naval Submarine.

Practices for Public Networks	**3.3.B:** Explain why segmentation increases security.	Segmentation isolates traffic to prevent lateral movement, allows for diverse security policies across zones, and enables port security to prevent MAC flooding.	Students use a diagram to recommend security features for different LANs in Scenario 3C, demonstrating knowledge of VLANs, subnets, and screened subnets (DMZ).
DAY 7-10 3.4 Firewalls	**3.4.A:** Identify types of network firewalls.	Types include stateless (header-based filtering), stateful (dynamic packet filtering), and next-generation firewalls (NGFW) which offer deep packet inspection and application-type filtering.	**Scenario 3A Artifacts:** Students determine placement and configure Firewalls A and B for Scenario 3A. They must demonstrate proper ACL rule precedence to allow specific traffic (e.g., SSH, HTTP) while blocking malicious requests.
	3.4.B: Explain how firewalls use Access Control Lists (ACLs).	An Access Control List (ACL) permits or denies traffic based on direction, IP address, port, or service, with rules executed in a specific precedence order.	
	3.4.C: Determine placement and configure firewalls.	Firewalls should be placed at every point of ingress/egress between internal segments and the public internet. Configuration involves defining specific rules (e.g., Allow Inbound TCP port 22) to meet organizational security requirements.	
DAY 11-14 3.5 Detecting Network Attacks	**3.5.A:** Identify types of automated security tools used to detect network attacks.	Tools include NIDS (detection/alerting), NIPS (prevention/blocking), and SIEM systems (log aggregation and pattern analysis).	**Scenario 3B Detection Task:** Students analyze packet captures and logs to identify indicators of compromise (IoCs). They evaluate the impact of signature-based vs. anomaly-based detection, considering factors like false positives and alert fatigue.
	3.5.B: Explain how organizations can leverage artificial intelligence (AI) to enhance threat detection and response.	AI algorithms use probabilistic calculations to classify massive amounts of data as malicious or normal, helping to prevent alert fatigue.	
	3.5.C: Determine a network detection method.	Methods include signature-based (known patterns), anomaly-based (deviations from a baseline), or hybrid detection.	
	3.5.D: Evaluate the impact of a network detection method.	Impacts are evaluated based on speed, cost, and the rates of false positives (causing alert fatigue) versus false negatives (adversaries bypassing detection).	
	3.5.E: Apply detection techniques to identify indicators of network attacks by analyzing log files.	Techniques include signal triangulation for evil twins, scanning for EM noise for jamming, and monitoring for duplicate MAC addresses or ICMP spikes to find ARP poisoning or Smurf attacks.	

Unit Title:

Unit 4: Securing Devices

Relevant Standards: Bold indicates priority

Skill 1: Analyze Risk - Evaluate risk to organizational assets.

1.C Evaluate, with and without the support of AI, the likelihood and impact of risks.

1.D Document, with and without the support of AI, the likelihood and impact of risks.

Skill 2: Mitigate Risk - Implement protective and deterrent security controls.

2.A Identify security controls, and explain how they mitigate risks.

2.B Determine layered security controls that address vulnerabilities.

2.C Evaluate, with and without the support of AI, the impact of protective risk-management strategies.

2.D Implement and log mitigations with and without the support of AI.

Skill 4: Collaborate - Work with others and AI to accomplish a task.

4.A Develop clear, shared team objectives related to a cybersecurity task.

4.B Determine clear roles and responsibilities for members of a team working to accomplish a cybersecurity task.

4.C Implement AI as a collaboration tool individually and as a group.

4.D Complete assigned work to accomplish a collaborative cybersecurity task.

Essential Question(s):	**Enduring Understanding(s):**
• How do the diverse types of computing devices expand the attack surface and create unique vulnerabilities for adversaries to exploit? • In what ways do different types of malware, such as ransomware, rootkits, or fileless malware, enable adversaries to damage, disrupt, or gain unauthorized control of a device? • Why is cryptographic hashing fundamental to secure password storage, and how does the use of "salts" protect against attacks like rainbow tables? • How do various authentication factors (knowledge, possession, biometric, and location) and multifactor authentication (MFA) effectively verify user identity and prevent impersonation? • What is the role of managerial controls (such as Acceptable Use Policies) and host-based technical controls (like firewalls and anti-malware) in a defense-in-depth strategy? • How can security professionals identify and distinguish between host-based, file-based, and behavior-based indicators of compromise (IoCs) when analyzing device logs? • What are the trade-offs involved in selecting detection methods, specifically regarding the impact on device performance, cost, and the rate of false positives?	• Computing devices are the primary targets for adversaries because they store, process, and transmit all digital data. • The rapid integration of embedded computers into everyday items has led to a rapid growth in device vulnerabilities, requiring defenders to assess risk across a much broader range of hardware than traditional computers. • Securing individual devices is a critical layer in a defense-in-depth strategy; it provides a final opportunity to stop an adversary who has already bypassed physical and network-layer controls. • Cryptographic hash functions are fundamental to security because they produce a fixed-length output that is repeatable and one-way, allowing for the secure storage of passwords and the verification of data integrity without storing plaintext information. • Robust security requires verifying user identity through various factors (knowledge, possession, biometric, and location); implementing Multifactor Authentication (MFA) is significantly more secure than single-factor methods because it requires at least two separate proofs of identity. • Keeping a device's operating system and applications updated with patches is one of the most effective ways to prevent adversaries from taking advantage of known vulnerabilities. • Defenders can identify that a device has been compromised by analyzing Indicators of Compromise (IoCs) found in system logs, such as unusual file modifications, unexpected processes, or failed login patterns in authentication logs. • Organizations must evaluate detection methods based on cost, impact on device performance, and the trade-off between false positive rates (which cause alert fatigue) and the ease with which an adversary can bypass the system.
Demonstration of Learning:	**Pacing for Unit**

Authentic unit scenarios designed to connect cybersecurity concepts to real-world personal security situations (see Lesson Sequence). Formal demonstration of learning is measured through the AP Exam • Multiple Choice: Weighs Skill Category 1 (Analyze Risk), Skill Category 2 (Mitigate Risk), and Skill Category 3 (Detect Attacks) equally at 25–40% each across the entire course content. • Free-Response Question (FRQ): Unit 4 is a primary focus of the "Device Security Analysis" FRQ. In this section, students must analyze simulated sources to identify security issues and describe how specific configuration changes would impact the device and its users.	16 Block Periods • Topic 4.1: Device Vulnerabilities and Attacks: ~ 6 Blocks • Topic 4.2: Authentication: ~ 3 Blocks • Topic 4.3: Protecting Devices: ~ 3 Blocks • Topic 4.4: Detecting Attacks on Devices: ~ 4 Blocks
Family Overview (link below)	**Integration of Technology:**
AP Cybersecurity Family Overview	• Internet of Things (IoT) and Embedded Systems • Mobile and Server Infrastructure • Hashing Algorithms • Multifactor Authentication (MFA) • Endpoint Defense and Configuration Tools • Host-Based Firewalls • Anti-Malware Systems • Automated Patching • Connected Farm Equipment • Authentication Hardening • Manufacturing Forensics
Unit-specific Vocabulary:	**Aligned Unit Materials, Resources, and Technology (beyond core resources):**
• Servers • Personal Computers • Handheld Computers • Embedded Computers • Internet of Things (IoT) • BIOS / UEFI: Basic Input Output System or Unified Extensible Firmware Interface • Malware • Virus • Worm • Trojan • RAT (Remote Access Trojan) • Ransomware • Spyware • Keylogger • Logic Bomb • Rootkit • Fileless Malware • Cryptographic Hash Function • Collision • Plaintext • Salt • Multifactor Authentication (MFA) • Password Spraying • Credential Stuffing	N/A

• Rainbow Table Attack • Managerial Controls • Patch • Host-Based Firewall • Anti-Malware • Indicator of Compromise (IoC) • Authentication Logs (Auth Logs) • Host-Based IoC • File-Based IoC • Behavior-Based IoC • EDR (Endpoint Detection and Response)	
Opportunities for Interdisciplinary Connections:	**Anticipated misconceptions:**
• Precision Agriculture: Students research how internet-connected machinery, such as automated irrigation systems and milking machines, relies on onboard computers and GPS for remote maneuvering and operation. • Food Security: Analyzing vulnerabilities in farming equipment connects to larger issues of national food supply stability and the impact of cyberattacks on critical agricultural infrastructure. • Medical Equipment Security: Students examine the vulnerabilities of embedded computers within life-critical devices, such as pacemakers, insulin pumps, IV pumps, and MRI scanners. • Biometrics: The study of authentication factors includes biometric factors such as iris or retina scans and facial recognition, connecting cybersecurity to biological traits and physiology. • Cryptographic Hashing: Students study the properties of cryptographic hash functions (like SHA-256), exploring mathematical algorithms that take binary data of arbitrary length and produce a fixed-length string. • Probability and Logic: Learning about collisions (when two different inputs produce the same hash) and the keyspace of encryption algorithms involves statistical reasoning and binary logic. • Organizational Policy: Students analyze and develop managerial controls, such as Acceptable Use Policies (AUP), Password Policies, and Software Installation Policies, which govern professional behavior and legal compliance. • Risk Assessment: The unit mirrors professional business auditing by requiring students to document risks based on likelihood and severity, often measured by financial, reputational, or operational impact. • Infrastructure Management: Students learn about the specialized computers that operate critical infrastructure, such as circuit breakers at electrical substations and pumps at water treatment plants. • Industrial Forensics: Scenario 4C places students in the role of a forensic analyst for a manufacturing company, where they must protect industrial control environments from lateral movement following a breach.	• Internet of Things (IoT) as "Non-Computing" Devices • Confusing Hashing with Encryption • The Scope of Account Lockout Policies • Misunderstanding Multi-Factor Authentication (MFA) Factors. The "Best" Detection Method Fallacy • All Malware Is Contained in Files • Overestimating the Security of Mandatory Password Changes • Technical Application Errors (Permissions and Logs) • Misinterpreting Permission Bits • Conflating Authentication with Filtering
Connections to Prior Units:	**Connections to Future Units:**

- Integration into the Defense-in-Depth Model: Unit 4 represents a critical layer in the defense-in-depth (layered defense) strategy introduced in Unit 2. While Unit 2 focuses on the physical perimeter and Unit 3 on the network layer, Unit 4 focuses on the device layer. This unit teaches students that securing individual devices provides a final opportunity to stop an adversary who has already bypassed physical and network-layer controls.
- Application of the Risk Assessment Framework:The formal risk assessment process defined in Unit 2 is the exact framework students apply to devices in Unit 4. Students move from assessing physical risks (like an unlocked door) to technical device risks (like an unpatched operating system or an open telnet port).
- Evolution of Authentication and Identity Verification: Unit 4 builds upon the foundational security principles introduced in Unit 1:
    - Weak Authentication: While Unit 1 introduces the concept of weak passwords and unauthorized logins from a personal perspective, Unit 4 explores the technical mechanics of cryptographic hashing, salting, and rainbow table attacks.
    - Multifactor Authentication (MFA): Unit 1 introduces MFA as a personal tool. Unit 4 expands this into a technical requirement for organizational security, categorizing the specific factors used (knowledge, possession, biometric, and location).
- Progression of Log Analysis and Detection: The skill of identifying indicators of compromise (IoCs) through digital evidence is a continuous thread throughout the course:
    - Unit 1: Students analyze digital logs for unauthorized website logins.
    - Unit 3: Students analyze network log files and packet captures for network-based attacks.
    - Unit 4: Students refine these skills by analyzing authentication logs (auth logs) to identify host-based threats, such as password spraying or credential stuffing.
- Technical Logic of Firewalls: Unit 4 introduces host-based firewalls, which apply the same technical logic as the network-based firewalls studied in Unit 3. Students use the same principles of Access Control Lists (ACLs) and rule precedence (where the first matching rule is executed) to permit or deny traffic for a single device based on IP, port, and protocol.
- Managerial and Technical Controls: The classification of security controls (preventative, detective, and corrective) and control types (physical, technical, and managerial) from Unit 2 remains the standard for Unit 4.
    - Managerial Controls: Students expand on the policy work from Units 2 and 3 by developing device-specific policies, such as Acceptable Use
- Progression to the Final Defense-in-Depth Layer: Unit 4 represents the device layer of the defense-in-depth model. This connects directly to Unit 5, which addresses the final and most critical layers: applications and data. Students learn that while a device may be hardened (Unit 4), the ultimate goal of an adversary is often to steal, modify, or deny access to the data stored on that device (Unit 5).
- Evolution of Cryptographic Concepts
    - From Hashing to Encryption: In Unit 4, students master cryptographic hashing primarily for secure password storage and integrity checks.
    - Advanced Cryptography in Unit 5: Unit 5 builds on this by introducing symmetric and asymmetric encryption. Students apply their understanding of one-way hashes from Unit 4 to more complex two-way encryption processes used to protect data at rest and in transit.
- Scaling Access Control and Authorization
    - Unit 4 Hardening: Students learn to technically harden a device through login settings, such as password complexity and account lockout policies.
    - Unit 5 Access Models: Unit 5 expands these basic login configurations into formal Access Control Models, including Role-Based (RBAC), Discretionary (DAC), and Mandatory Access Control (MAC). The Linux-based permission skills (chmod, ls -l) introduced in Unit 4 assessments are core requirements for Scenario 5A.
- Maturation of Log Analysis and Detection: The practice of identifying Indicators of Compromise (IoCs) becomes more sophisticated in the transition to Unit 5:
    - Unit 4 focuses on host-based and behavior-based IoCs found in auth.log, such as password spraying or credential stuffing.
    - Unit 5 shifts to application-based IoCs. Students use the analysis skills they practiced in Unit 4 to identify more complex application-level attacks in web server logs, such as SQL injection, Cross-Site Scripting (XSS), and directory traversal.
- Progression of Managerial Controls:The policy-writing skills developed in Unit 4 are applied to more specialized data-handling contexts in Unit 5:
    - Unit 4 Policies: Focused on device behavior (Acceptable Use Policy) and local access (Password Policy).
    - Unit 5 Policies: Focused on specialized data protection, including Cryptography Policies and Web Application Security Policies.
- Realizing the Consequences of Lateral Movement: Unit 4 Scenario 4C requires students to analyze logs specifically to prevent a breach from spreading from a business network to a manufacturing network (lateral movement). This connects to Unit 5, where students see that the ultimate destination of lateral movement is typically to reach high-value, sensitive data (such as proprietary R&D) that must be protected with the application-level controls studied in the final unit.

Policies (AUP), Password Policies, and Software Installation Policies.
    - Technical Controls: Unit 4 focuses on host-level mitigations like anti-malware software and automated patching, which serve as the final technical barriers for a device.
- Continuous Use of AI as a Collaboration Tool: Building on Skill 4.C introduced in Unit 1, Unit 4 continues to integrate Artificial Intelligence as a collaborative partner. Students use AI to help research device vulnerabilities and analyze complex system logs, continuing the theme from Unit 3 where AI is used to sort through millions of data points to identify malicious patterns.

Differentiation through *Universal Design for Learning*

	Engagement	Representation	Action & Expression
4.1A	Endpoint sorting activity categorizing servers, IoT, embedded, and mobile devices.	Visual hardware/OS matrix mapping computing devices to attack surfaces.	Build an enterprise asset inventory list or create an interactive endpoint taxonomy graphic.
4.1B	"Malware Zoo" interactive exploration examining ransomware, trojans, worms, and spyware.	Taxonomy tree mapping malware categories to infection channels and payloads.	Design a malware identification poster or produce a podcast episode on malware defense.
4.1C	Demonstration of unpatched software exploits in isolated virtual machines.	Execution flow diagram showing buffer overflows and memory exploitation.	Write an endpoint exploit summary or record a screencast explaining exploitation.
4.1D	Perform an OS security audit on a sample image using CIS Benchmarks.	Scorecard rubric grading OS configurations, open services, and patch levels.	Produce an Endpoint Risk Assessment Report or present audit findings via video.
4.2A	Hands-on lab generating SHA-256 hashes to observe the avalanche effect.	Flowchart visual: Plaintext + Salt -> Cryptographic Hash Function -> Stored Hash.	Write an explanatory guide on hashing vs. encryption or record a hashing tool demo.
4.2B	Demonstration of offline hash cracking using weak vs. strong wordlists in a sandbox.	Conceptual diagram illustrating rainbow table attacks and unsalted hash risks.	Deliver a presentation on hash protection or write a whitepaper on salting.
4.2C	Scenario evaluation selecting Kerberos, OAuth, Biometrics, or RADIUS.	Comparison matrix evaluating authentication methods across security and usability.	Write an authentication architecture proposal or design a decision-tree graphic.
4.2D	Hands-on OS lab configuring lockout thresholds, complexity rules, and timeouts.	Screenshot walkthrough of Windows Group Policy or Linux PAM settings.	Submit a security policy configuration file or create an OS hardening lab guide.
4.3A	Policy evaluation review analyzing BYOD and Mobile Device Management (MDM) rules.	Policy chart contrasting BYOD, COPE, and CYOD management models.	Draft an MDM/BYOD corporate policy document or record an employee onboarding video.
4.3B	Demonstration comparing signature scanning vs. behavioral EDR blocking malware.	Dual-stream diagram showing malware execution interception and quarantine actions.	Write an endpoint security software recommendation memo or record a video explanation.
4.3C	Historical breach case study on unpatched system exploits (e.g., WannaCry).	Lifecycle diagram: Vulnerability Discovery -> Patch Release -> Testing -> Deployment.	Create a patch management policy guide or record a public service announcement video.
4.3D	Sandbox lab configuring Windows Defender Firewall or Linux ufw port rules.	Visual configuration guide mapping host firewall rules to specific ports.	Submit a host firewall hardening script or present a configuration walkthrough.
4.4A	Threat-hunting exercise identifying abnormal process tree executions.	Visual process tree diagram highlighting normal vs. malicious execution chains.	Write an endpoint threat-hunting guide or present a live process analysis demonstration.
4.4B	Selection evaluation choosing between Sysmon, OS audit logging, and EDR agents.	Selection matrix mapping telemetry requirements to specific logging tools.	Draft an endpoint detection strategy or build a tool selection presentation.

4.4C	Simulation measuring endpoint resource overhead (CPU/RAM) vs. logging verbosity.	Line graph balancing host performance impact against security visibility.	Write a performance-versus-security trade-off evaluation report.
4.4D	Analyze Event Logs (Event ID 4625) or Linux /var/log/auth.log for intrusion signs.	Event Log Cheat Sheet highlighting critical Event IDs and log parameters.	Create an event log forensic report or deliver a log analysis presentation.

Supporting Multilingual/English Learners (*CELP standards*)

	Emerging	Expanding	Bridging
4.1A	Label images of computing devices (e.g., *servers, endpoints, mobile devices, IoT, embedded systems*).	Classify computing devices by function and risk level using categorized graphic organizers.	Analyze diverse computing device hardware and firmware architectures for organizational security implications.
4.1B	Match malware types (e.g., *ransomware, spyware, Trojan, worm, rootkit*) to visual cartoons/icons and simple definitions.	Describe malware characteristics using classification matrices and guided summary frames.	Differentiate advanced malware behavior (e.g., fileless malware, polymorphic viruses) and propagation vectors.
4.1C	Trace an attack path diagram showing an unpatched system vulnerability leading to device compromise.	Explain how attackers exploit unpatched software or OS flaws using cause-and-effect sentence frames.	Analyze zero-day vs. known vulnerability exploitation techniques on endpoint operating systems.
4.1D	Complete a guided device inventory risk checklist using visual vulnerability indicators.	Document endpoint security risks using structured template fields (*Asset, Threat, Severity, Risk Level*).	Conduct comprehensive endpoint risk evaluations and generate formal risk documentation reports.
4.2A	Sequence a visual diagram: *Plaintext Password $\rightarrow$ Hash Function $\rightarrow$ Fixed Length Hash Digest*.	Explain password hashing and one-way functions using guided technical paragraph frames (*"Hashing transforms passwords into..."*).	Explain the mathematical and cryptographic properties of hashing algorithms (e.g., SHA-256) and collision resistance.
4.2B	Match attack methods (e.g., *rainbow tables, dictionary attacks, pass-the-hash*) to basic visual descriptions.	Explain how attackers crack hashes using rainbow tables or brute force through explanatory writing frames.	Contrast password cracking techniques and evaluate the effectiveness of cryptographic salts and key stretching (e.g., bcrypt).
4.2C	Sort authentication factors into three columns: *Something You Know, Something You Have, Something You Are*.	Classify multi-factor authentication methods and explain why multi-factor is superior to single-factor using comparative language.	Evaluate enterprise authentication frameworks (e.g., SAML, OAuth, PKI) for various device management scenarios.
4.2D	Follow step-by-step visual screenshots to configure password length, lockout thresholds, and screen timeouts in OS settings.	Configure endpoint security policies (e.g., Windows Group Policy / Linux PAM) and document configuration steps.	Script and enforce system-wide secure authentication and account lockout policies across enterprise devices.
4.3A	Match managerial device controls (e.g., *MDM policies, BYOD policy, asset tracking*) to workplace scenario cards.	Describe device management policies using policy language (*"Employees are required to...", "Unauthorized devices are..."*).	Formulate comprehensive Mobile Device Management (MDM) and Acceptable Use Policies (AUP) for enterprise endpoints.
4.3B	Complete fill-in sentences with a word bank explaining how anti-malware scans and isolates bad files.	Explain how anti-malware protects systems using technical verbs (*scans, quarantines, detects, updates signatures*).	Evaluate signature-based vs. heuristic/behavioral anti-malware solutions and their operational trade-offs.
4.3C	Sequence a diagram showing *Vulnerability Discovered $\rightarrow$ Patch Released $\rightarrow$ Patch Installed $\rightarrow$ System Secured*.	Write a short persuasive paragraph explaining why regular patching prevents malware exploitation using key vocabulary.	Formulate enterprise patch management lifecycle strategies, prioritizing critical security updates.
4.3D	Identify common endpoint attack symptoms (e.g., *high CPU usage, unexpected pop-ups, modified system files*) on an infographic.	Describe endpoint indicators of compromise (IoCs) in structured paragraphs using technical terminology.	Synthesize endpoint telemetry (process trees, memory dumps, registry changes) to detect host breaches.
4.4A	Match endpoint detection controls (e.g., *EDR, File Integrity Monitoring, Host IDS*) to corresponding threat descriptions.	Recommend endpoint detection controls for specific threat scenarios using justification sentence starters.	Architect an integrated endpoint detection strategy incorporating EDR, FIM, and centralized logging.

4.4B	Sort event scenarios into *High Impact / Immediate Alert* vs. *Low Impact / Log Only* visual bins.	Evaluate the effectiveness and system overhead impact of various host detection mechanisms using guided templates.	Perform trade-off analysis between detection sensitivity, resource consumption, and business operational disruption.
4.4C	Highlight suspicious log entries (e.g., *failed root login attempts, unauthorized PowerShell commands*) in annotated OS log files.	Analyze system log files (e.g., Windows Event Viewer, /var/log/auth.log) using guided search prompts and record IoCs.	Query and analyze raw host logs using SIEM search tools to construct incident response timelines.
4.4D	Label images of computing devices (e.g., *servers, endpoints, mobile devices, IoT, embedded systems*).	Classify computing devices by function and risk level using categorized graphic organizers.	Analyze diverse computing device hardware and firmware architectures for organizational security implications.

Unit Outline

Lesson Sequence	Learning Target	Success Criteria	Assessment
DAY 1-6 4.1 Device Vulnerabilities & Attacks	**4.1.A:** Identify types of computing devices.	Devices include servers, personal computers (laptops/desktops), handhelds (smartphones/tablets), embedded computers (specialized machines), and Internet of Things (IoT) devices (smart appliances, medical equipment, infrastructure pumps).	**Scenario 4A: Secure Connected Farm Equipment**; AI-supported risk evaluation tools. **Scenario 4A Part 1:** Students research how an adversary might exploit internet-connected farm equipment (IoT) and assess the risk level (likelihood and impact) for specific vulnerabilities.
	4.1.B: Identify types of malware.	Malware types include viruses (user-activated), worms (self-spreading), trojans (disguised as harmless), ransomware (file encryption), spyware, keyloggers, logic bombs, rootkits (operating system-level control), and fileless malware (RAM-based).	
	4.1.C: Explain exploitation of device vulnerabilities.	Vulnerabilities include unpatched software, weak authentication, lack of BIOS/UEFI protection (which allows booting into "recovery mode"), enabled autorun on external drives, open ports, and a lack of host-based firewalls or anti-malware.	
	4.1.D: Assess/document device risks.	Risks are classified as high (compromising sensitive data or critical operations like unpatched email servers), moderate (weak authentication for management systems), or low (low-impact vulnerabilities like an open telnet port on a standard laptop).	
DAY 7-9 4.2 Authentication Foundations	**4.2.A:** Explain password hashing.	The cryptographic hash function produces a fixed-length string that is collision-resistant, repeatable, and one-way (cannot be reversed). Hashing prevents plaintext password storage, while salting (adding random bits) ensures unique hashes for identical passwords.	**Scenario 4B: Aceshack Settings**; Password managers. **Scenario 4B:** Students log on as administrators to configure local security settings, such as password complexity, minimum length, and account-lockout policies to prevent brute-force attacks
	4.2.B: Explain password attack exploitation.	Attacks include online (active portal attempts), offline (running automated hash-cracking against stolen databases), password spraying (one password vs. many users), credential stuffing (using leaked/default credentials), and rainbow table attacks (precomputed hash lists).	
	4.2.C: Determine authentication types.	Authentication factors include knowledge (passwords/PINs),	

		possession (access cards/tokens), biometric (fingerprints/facial recognition), and location (GPS/IP address). Multifactor authentication (MFA) requires at least two separate factors.	
	4.2.D: Configure secure login settings.	Secure configurations include password complexity, minimum length, maximum age (periodic resets), password history (preventing reuse), and account lockout policies.	
DAY 10-12 4.3 Mitigating Device Risk	**4.3.A:** Identify managerial device controls.	Managerial controls include Acceptable Use Policies (AUP), Password Policies, and Software Installation Policies that define permitted activities and required security standards for organizational devices.	**Scenario 4A Part 2:** Students determine mitigation strategies for farm equipment, recommending host-based firewalls, anti-malware, and Acceptable Use Policies (AUP) to produce a report for management.
	4.3.B: Explain anti-malware software benefits.	Anti-malware uses signatures (indicators) to scan, quarantine, and remove malicious files that match its database.	
	4.3.C: Explain the importance of system updates.	Updates, or patches, fix known vulnerabilities, preventing adversaries from using documented exploits.	
	4.3.D: Configure a host-based firewall.	Host-based firewalls protect single devices using Access Control Lists (ACLs) that apply the first matching rule in sequence to permit or deny inbound and outbound traffic based on IP, port, or service.	
DAY 13-16 4.4 Detecting Attacks on Devices	**4.4.A:** Explain how to detect attacks.	Indicators of Compromise (IoCs) can be host-based (unexpected processes/unauthorized settings), file-based (malicious file hashes/paths), or behavior-based (failed logins/unusual times or locations).	**Scenario 4C: Dynamic Forensic Analyst logs**; EDR (Endpoint Detection and Response) service descriptions; AI for anomaly detection. **Scenario 4C:** Students analyze authentication logs for signs of password spraying or credential stuffing on a manufacturing network and submit a forensic report of findings.
	4.4.B: Determine detection controls.	Criteria for detection methods include performance (anomaly-based tools use more memory/CPU), cost (software licensing or EDR services), and the sensitivity of the device.	
	4.4.C: Evaluate the impact of detection.	Factors include detection speed, impact on device performance, and the trade-off between false positives (low in signature-based tools) and the ease of bypass for adversaries.	
	4.4.D: Apply detection techniques to log files.	Techniques include identifying password spraying (many users failing within seconds from one IP) or credential stuffing (repeated attempts of default user:password combos). Note that offline attacks cannot be detected because they occur on the adversary's computer.	

Unit Title:

Unit 5: Securing Applications and Data

Relevant Standards: Bold indicates priority

Skill 2: Mitigate Risk - Implement protective and deterrent security controls.

2.A Identify security controls, and explain how they mitigate risks.
2.B Determine layered security controls that address vulnerabilities.
2.D Implement and log mitigations with and without the support of AI.

Skill 3: Detect Attacks - Implement detection methods, monitor systems, and analyze evidence.

3.B Determine strategies and methods to detect attacks.
3.D Detect and classify cyberattacks by analyzing digital evidence with and without the support of AI.

Skill 4: Collaborate - Work with others and AI to accomplish a task.

4.A Develop clear, shared team objectives related to a cybersecurity task.
4.B Determine clear roles and responsibilities for members of a team working to accomplish a cybersecurity task.
4.C Implement AI as a collaboration tool individually and as a group.
4.D Complete assigned work to accomplish a collaborative cybersecurity task.

Essential Question(s):

- How does an adversary's ultimate goal of stealing, modifying, or denying access to data influence their choice of application-level attack methods, such as SQL injection, Cross-Site Scripting (XSS), or buffer overflows?
- How do the various states of data dictate the degree of security controls and cryptographic methods required to protect its confidentiality and integrity?
- In what ways do legal and regulatory frameworks, such as HIPAA for health information and PCI-DSS for payment information, mandate specific data classification and handling practices for organizations?
- How do different access control models implement the principle of least privilege to restrict unauthorized operations on sensitive files?
- What are the fundamental differences between symmetric and asymmetric cryptography, and how does the secure management of private keys impact the security of an entire encrypted system?
- Why are the principles of "secure by design" and "security by default" critical for software developers, and how does user input sanitization serve as a primary defense against directory traversal and injection attacks?
- How can security analysts differentiate between normal user behavior and indicators of compromise (IoCs) in accounting and web server logs to detect active application-layer attacks?
- What are the operational impacts and technical trade-offs of using automated detection tools like honeypots and Data Loss Prevention (DLP) compared to retrospective log analysis and hash verification?

Enduring Understanding(s):

- Data is the core of the digital world, and stealing, modifying, or denying access to data is the primary end goal for most adversaries.
- The value and sensitivity of data are not uniform; the perceived value and regulatory classifications (such as PII, PHI, or PCI) directly influence the risk assessment and the degree of security controls required.
- Effective security requires distinct strategies for data in different states: at rest (stored), in transit (moving), and in use (processing).
- Organizations must enforce strict access control models to uphold the principle of least privilege, ensuring users have only the minimum access necessary for their roles.
- Cryptography is the primary tool for maintaining confidentiality; symmetric encryption uses a single shared key, while asymmetric encryption uses public and private key pairs to allow secure communication without prearranged secrets.
- Cryptographic hash functions are vital for ensuring data integrity; because hashes are repeatable and sensitive to even minor changes, they allow defenders to detect if a file has been altered by an adversary.
- Securing applications requires moving beyond "add-on" features toward "secure by design" and "security by default" principles, with user input sanitization serving as a critical defense against injection and traversal attacks.
- Defenders must utilize a combination of real-time tools and retrospective accounting log analysis to identify indicators of compromise (IoCs) and unauthorized access patterns.

Demonstration of Learning:

Authentic unit scenarios designed to connect cybersecurity concepts to real-world personal security situations (see Lesson Sequence).

Formal demonstration of learning is measured through the AP Exam

Pacing for Unit

19 Block Periods

- Topic 5.1: Application and Data Vulnerabilities and Attacks: ~ 3 Blocks
- Topic 5.2: Protecting Applications and Data: Managerial Controls and Access Controls: ~ 4 Blocks

• Multiple Choice: Weighs Skill Category 1 (Analyze Risk), Skill Category 2 (Mitigate Risk), and Skill Category 3 (Detect Attacks) equally at 25–40% each across the entire course content. • Free-Response Question (FRQ): Security Analysis FRQ directly assesses Unit 5 skills. Students must analyze simulated sources, such as file-system permissions and application log files, to identify security issues and write the correct commands to remediate vulnerabilities.	• Topic 5.3: Protecting Stored Data with Cryptography: ~ 3 Blocks • Topic 5.4: Asymmetric Cryptography: ~ 3 Blocks • Topic 5.5: Protecting Applications: ~ 2 Blocks • Topic 5.6: Detecting Attacks on Data and Applications: ~ 4 Blocks
Family Overview (link below)	**Integration of Technology:**
AP Cybersecurity Family Overview	• Encryption Suites • Secure Messaging • Hashing Utilities • Linux Permissions • Role-Based (RBAC) models • Discretionary (DAC) models • Mandatory (MAC) models • Artificial Intelligence (AI) as a Technical Partner • Nginx web server logs and accounting logs • Deployment of honeypots and Data Loss Prevention (DLP) services • Intrusion Prevention Systems (IPS)
Unit-specific Vocabulary:	**Aligned Unit Materials, Resources, and Technology (beyond core resources):**
• Data at Rest • Data in Transit • Data in Use: • PII (Personally Identifiable Information). • PHI (Protected Health Information) • PCI (Payment Card Information) • Subject • Object • Role-Based Access Control (RBAC) • Rule-Based Access Control (RuBAC) • Discretionary Access Control (DAC) • Mandatory Access Control (MAC) • Principle of Least Privilege • Data Validation • Input Sanitization • SQL Injection • Cross-Site Scripting (XSS) • Buffer Overflow • Directory Traversal: • Plaintext • Ciphertext • Symmetric Encryption • Asymmetric Encryption • Keyspace • Block Encryption • Stream Encryption • Accounting • Honeypot • DLP (Data Loss Prevention • Retrospective Analysis	N/A
Opportunities for Interdisciplinary Connections:	**Anticipated misconceptions:**

• Privacy Law: Students study the Privacy Act of 1974 and the Children's Online Privacy Protection Act (COPPA) in the context of protecting Personally Identifiable Information (PII). • Healthcare Regulation: The unit introduces HIPAA (1996), which mandates strict security for Protected Health Information (PHI) • Financial Standards: Students learn about the Payment Card Industry Data Security Standard (PCI DSS), which regulates how organizations must store and transmit credit card data. • Proprietary Research: Students act as security team members for a pharmaceutical company tasked with protecting research on a new product, connecting cybersecurity to the biotech R&D process and the importance of intellectual property. • Bioethics: The classification of health records as highly sensitive (PHI) connects to broader ethical discussions about patient privacy and medical confidentiality. • Algorithmic Functions: Students explore the mechanics of symmetric and asymmetric encryption, which rely on mathematical algorithms to hide information in ciphertext • Mathematical Inverses: The study of asymmetric cryptography involves learning about public and private key pairs, which are mathematical inverses where one key reverses the operation of the other. • Organizational Policy: Students analyze and identify the components of Cryptography Policies and Web Application Security Policies, mirroring the work of business compliance officers • Operational Risk: The curriculum connects data classification (at rest, in transit, in use) to business priorities, teaching students to prioritize security controls based on the criticality and value of the data to an organization • Critical Infrastructure: Students simulate security engineers at a utility company that owns power generating plants, exploring the necessity of secure communication for maintaining the stability of national energy systems.	• Public vs. Private Key Usage • Misinterpreting Linux Permission Bits • Entity Confusion • The "+" Symbol • Hashing vs. Encryption Purposes • "Secure by Design" as a Post-Development Feature • The Scope of Input Sanitization • Directory Traversal as "Normal" Navigation • Data State Protection Fallacies • The "Authenticity" of Honeypots
Connections to Prior Units:	**Connections to Future Units:**
• Integration into the Defense-in-Depth Model: Unit 5 represents the innermost layer of the defense-in-depth (layered defense) strategy introduced in Unit 2. While prior units focused on the physical perimeter (Unit 2), the network (Unit 3), and the device (Unit 4), Unit 5 addresses the ultimate objective of most adversaries: the applications and data itself. Students learn that if all other layers are bypassed, these final controls are the last line of defense. • Application of the Risk Assessment Framework: The formal risk assessment process defined in Unit 2 is applied directly to data in Unit 5. Students move from assessing physical or network risks to evaluating the risk to specific data classifications, such as: ○ PII (Personally Identifiable Information): Covered by laws like the Privacy Act.	N/A

- PHI (Protected Health Information): Regulated by HIPAA.
- PCI (Payment Card Information): Regulated by industry standards.

- Evolution of Cryptographic Concepts: Unit 5 builds upon the cryptographic foundations laid in Unit 4:
  - From Hashing to Encryption: In Unit 4, students mastered cryptographic hashing for password storage and integrity. Unit 5 expands this into two-way encryption for maintaining confidentiality, teaching both symmetric (AES) and asymmetric (RSA/ECC) algorithms.
  - Integrity Verification: The hashing skills from Unit 4 are used in Unit 5 as a detective control to verify if files have been altered by an adversary.
- Scaling Access Control and Authorization: Unit 5 evolves the basic login settings from Unit 1 and the local device hardening from Unit 4 into formal Access Control Models:
  - Models: Students apply the principles of least privilege using Role-Based (RBAC), Discretionary (DAC), and Mandatory Access Control (MAC) models.
  - Technical Skills: The Linux-style file permission skills (rwx) introduced in Unit 4 assessments are moved into active configuration in Unit 5 Scenario 5A, where students must use the chmod command to protect proprietary research.
- Maturation of Log Analysis and Detection: The practice of identifying Indicators of Compromise (IoCs) becomes its most sophisticated in Unit 5:
  - Progression: Students move from simple unauthorized logins (Unit 1) and network-based traffic patterns (Unit 3) to application-layer forensics.
  - Specific IoCs: Unit 5 requires students to find evidence of advanced attacks in web server logs, such as SQL injection control words (e.g., OR 1=1), XSS script tags, and directory traversal sequences (../).
- Protection Across Data States: Unit 5 expands on the concept of data in transit (the focus of Unit 3 network security) by introducing protection strategies for data at rest (stored on drives) and data in use (actively being processed). Students learn that data must be unencrypted to be used, necessitating the strict access controls studied earlier in the unit.
- Continuous Use of AI as a Collaboration Tool: Building on Skill 4.C introduced at the start of the course, Unit 5 continues to integrate Artificial Intelligence as a technical partner. Students use AI to help analyze application code for vulnerabilities and to summarize complex digital events in web server logs that are too vast for human review.

Differentiation through *Universal Design for Learning*

	Engagement	Representation	Action & Expression
5.1A	OWASP Top 10 interactive lab exploring software application exploits.	Flowcharts mapping software flaws (buffer overflows, injection) to system impact.	Create an application security awareness flyer or record a video briefing.
5.1B	Hands-on lab using WebGoat/Juice Shop executing SQL Injection (SQLi) and XSS.	Side-by-side code visual showing dynamic query building vs. parameterized queries.	Write a code vulnerability walkthrough or present an exploit analysis video.
5.1C	Threat-modeling exercise applying STRIDE to web application architectures.	STRIDE threat model template paired with a severity rating matrix.	Submit a completed STRIDE Threat Model report for a target web application.

5.2A	Sorting activity categorizing data states (Rest, Transit, Use) and sensitivity levels.	Grid mapping data classifications to appropriate security controls (TLS, AES).	Draft a Data Classification Standard document or design an organizational guide poster.
5.2B	Case study evaluation of Data Loss Prevention (DLP) and compliance frameworks.	Policy framework chart illustrating data retention, privacy, and DLP governance.	Write a corporate Data Privacy Policy memo or construct a compliance slide deck.
5.2C	Role-play exercise contrasting DAC, MAC, RBAC, and ABAC in enterprise scenarios.	Comparison matrix evaluating DAC, MAC, RBAC, and ABAC access models.	Design an Access Control Matrix for a healthcare or financial system model.
5.2D	Linux CLI lab configuring user file permissions (chmod, chown, POSIX ACLs).	Visual octal permissions diagram mapping rwx / 755 / 644 values.	Submit a bash script configuring Linux permissions or record a video walkthrough.
5.3A	Local file encryption lab using BitLocker or VeraCrypt to test unauthorized access.	Flowchart showing plaintext converted to ciphertext via encryption keys.	Draft an "Encryption at Rest" user guide or demonstrate file encryption in a video.
5.3B	Command-line lab using OpenSSL to encrypt/decrypt text files using AES-256.	Visual diagram illustrating shared secret key usage for encryption and decryption.	Submit an OpenSSL execution portfolio or write a technical secret key guide.
5.4A	"Public Key Exchange" activity sending encrypted notes between peers using GPG.	Key pair diagram (Public Key = Lock, Private Key = Key) illustrating workflows.	Construct a Public Key Infrastructure (PKI) flowchart or create a video lesson.
5.4B	Key space math challenge calculating brute-force times across 56-bit to 256-bit keys.	Exponential graph illustrating key bit length vs. computational brute-force entropy.	Write an analytical paper on cryptographic key strength or deliver a presentation.
5.4C	Hands-on CLI lab generating GPG key pairs, exchanging public keys, and decrypting messages.	Step-by-step workflow graphic showing GPG key generation and message signing.	Submit an encrypted and signed message portfolio or record a GPG screencast.
5.5A	Software critique activity evaluating weak default settings in commercial applications.	Principles graphic illustrating least privilege, fail-safe defaults, and defense in depth.	Draft a Secure Coding Standard document or deliver a presentation to mock developers.
5.5B	Web form lab submitting script payloads (<script>alert(1)</script>) to test sanitization.	Input pipeline diagram showing raw input -> sanitization/encoding -> execution.	Write code snippets demonstrating input validation or record an instructional video.
5.6A	Lab inspecting File Integrity Monitoring (FIM) tools and database activity logs.	Architecture diagram showing Database Activity Monitoring (DAM) and FIM alerts.	Create a data breach detection guide or write a data exfiltration forensic report.
5.6B	Selection scenario matching Web Application Firewalls (WAF) and DB auditing tools.	Matrix mapping attack types (SQLi, XSS, file tampering) to detection controls.	Propose an application detection strategy for a web application deployment.
5.6C	Analyze performance latency and false positive rates when running WAF in blocking mode.	Trade-off chart balancing web performance impact against threat detection coverage.	Deliver an impact evaluation presentation or write an executive technical review.
5.6D	"Tamper Detection Challenge" calculating MD5/SHA-256 hashes of modified files using sha256sum.	Side-by-side visual showing how a single character change alters the hash output.	Submit a file verification lab report or record a video tutorial on hashing.
5.6E	Web server log analysis lab searching access logs for SQLi payloads and directory traversal.	Color-coded HTTP log cheat sheet mapping status codes (200, 403, 500) and signatures.	Write an application incident report based on web log analysis or give a presentation.

Supporting Multilingual/English Learners (*CELP standards*)

	Emerging	Expanding	Bridging
5.1A	Match application attack types (e.g., *SQL injection, Buffer overflow, Cross-Site Scripting/XSS*) to visual code/web diagrams.	Explain how input vulnerabilities lead to unauthorized application control using cause-and-effect sentence frames.	Analyze application vulnerability mechanisms and trace how malicious payloads exploit memory or database logic.
5.1B	Trace data flow in a visual diagram showing malicious input bypassing input fields directly into a database.	Describe application exploitation steps using sequential transition words and technical vocabulary.	Detail exploit mechanisms across OWASP Top 10 web application vulnerabilities.

5.1C	Complete an application risk assessment worksheet using color-coded severity cards.	Write application risk summaries using a standardized template (*Vulnerability, Threat, Impact, Risk Score*).	Perform threat modeling (e.g., STRIDE framework) for web applications and document systemic data risks.
5.2A	Sort data items (e.g., *Public website text, Student SSNs, Medical records*) into classification buckets (*Public, Internal, Confidential, Restricted*).	Explain how data classification levels dictate security controls (encryption, access limits) using comparative structures.	Formulate an enterprise data classification matrix and map corresponding data lifecycle security requirements.
5.2B	Match managerial controls (e.g., *NDAs, Data Retention Policies, Separation of Duties*) to definition cards.	Describe administrative policies protecting sensitive application data using formal regulatory language.	Author data governance and privacy policy frameworks compliant with legal standards (e.g., FERPA, GDPR, Privacy Act).
5.2C	Match scenario cards to Access Control Models (*DAC, MAC, RBAC, ABAC*) using visual feature descriptions.	Recommend access control models (e.g., *Role-Based vs. Attribute-Based*) for organization scenarios using decision templates.	Evaluate organizational access requirements and design scalable Role-Based (RBAC) and Attribute-Based (ABAC) structures.
5.2D	Execute guided Linux file permission commands (chmod, chown) following a visual syntax guide card (rwx permissions table).	Configure Linux file permissions and ownership via command line, documenting permission numeric codes (chmod 750).	Manage complex POSIX file permissions and Access Control Lists (setfacl) on Linux systems to enforce least privilege.
5.3A	Match encryption concepts (e.g., *Plaintext + Key $\rightarrow$ Ciphertext*) to visual block diagrams.	Explain confidentiality protection via encryption using guided paragraphs ("*Encryption converts unreadable ciphertext so that...*").	Evaluate cryptographic security states (*Data at Rest, Data in Transit, Data in Use*) and corresponding protective schemes.
5.3B	Encrypt and decrypt short messages using a simple visual cipher wheel or tool (e.g., CyberChef Caesar/AES demo) with step-by-step guidance.	Demonstrate symmetric encryption concepts using shared secret keys and explain key distribution limitations using sentence starters.	Implement symmetric encryption algorithms (AES) in CLI/lab tools and analyze key management challenges.
5.4A	Use a key-pair visual diagram prompt card: "*To encrypt for Alice, use Alice's [Public Key]. To sign, Alice uses her [Private Key]*".	Explain key usage rules in asymmetric cryptography using conditional sentence frames ("*When sending a secret message to Bob, Alice uses...*").	Solve complex Public Key Infrastructure (PKI) scenario problems involving digital signatures, encryption, and non-repudiation.
5.4B	Compare key length visual charts showing time required to brute-force 56-bit vs. 128-bit vs. 256-bit keys.	Explain the relationship between key length, exponential combinations (2^n), and brute-force difficulty using structured prompts.	Quantify cryptographic strength computationally and explain how key length protects against modern brute-force systems.
5.4C	Encrypt/decrypt short messages using an interactive PKI demonstration web application with visual step-by-step prompts.	Execute asymmetric encryption/decryption tasks using tools (e.g., GPG) and document public/private key exchanges.	Generate PGP/GPG keypairs, manage key rings, and perform signed and encrypted file exchanges in CLI environments.
5.5A	Match security principles (*Secure by Design, Security by Default*) to visual example cards (e.g., *all ports closed by default*).	Explain *Secure by Design* and *Security by Default* principles using comparative graphic organizers.	Audit application deployment configurations against *Secure by Design* principles and recommend hardening strategies.
5.5B	Complete a visual contrast card showing raw input with malicious code vs. sanitized/escaped code input.	Explain how input sanitization prevents injection attacks using sentence frames ("*Sanitization neutralizes code by stripping...*").	Evaluate input validation, parameterization, and output encoding techniques across software development scenarios.
5.6A	Circle abnormal data access behaviors (e.g., *mass file downloads at 3 AM*) on a visual security dashboard mockup.	Describe indicators of data exfiltration and unauthorized access using targeted technical language.	Analyze data loss prevention (DLP) metrics and database audit logs to identify complex data breach attempts.
5.6B	Match application detection controls (e.g., *WAF, Database Activity Monitoring, DLP*) to threat scenario cards.	Select and justify application layer detection controls using decision matrix templates.	Design comprehensive application monitoring architectures integrating Web Application Firewalls (WAF) and SIEM logging.
5.6C	Sort impacts of detection methods into a visual chart (*System Latency, Blocked Legitimate Users, Caught Attacks*).	Evaluate trade-offs between strict application monitoring rules and system performance/usability using guided templates.	Conduct impact evaluations of WAF rule configurations balancing security efficacy against false-positive rates.

5.6D	Compare two MD5/SHA-256 hash strings side-by-side and indicate if they match or differ (*Same = Unaltered, Different = Altered*).	Verify file integrity by computing hash digests via command line (sha256sum) and writing verification statements.	Automate file integrity monitoring (FIM) scripts to detect unauthorized file modifications across system directories.
5.6E	Highlight web server log lines showing common attack patterns (e.g., ' OR '1'='1, <script>) in pre-formatted log sheets.	Analyze HTTP access logs (e.g., Apache/Nginx logs) to identify attack signatures and write incident summary reports.	Parse, filter, and analyze web application access and error logs to trace multi-stage web application compromises.

Unit Outline

Lesson Sequence	Learning Target	Success Criteria	Assessment
DAY 1-3 5.1 Application & Data Risks	**5.1.A:** Explain how adversaries can exploit application and file vulnerabilities to cause loss, damage, disruption, or destruction.	Adversaries can read unencrypted files if they have device access, exploit elevated administrative privileges on compromised accounts, or take advantage of weak access control settings to steal or destroy files.	Examples of SQLi, XSS, and directory traversal; AI-powered tools for risk evaluation. Students can identify injection-type attacks (SQLi, XSS) and buffer overflows. They produce a risk assessment for sensitive data, such as unencrypted jet engine specs, documenting likelihood and impact.
	5.1.B: Explain how application attacks exploit vulnerabilities.	Vulnerabilities include a lack of data validation and input sanitization. Specific attacks include SQL injection (inserting database commands), Cross-Site Scripting (XSS) (injecting malicious browser code), buffer overflows (overwriting memory), and directory traversal (using ../ sequences to access unauthorized system files)	
	5.1.C: Assess and document risks from application and data vulnerabilities.	Risks involve compromises to confidentiality, integrity, and availability. High risks involve highly sensitive or regulated data such as PHI or PII stored on unencrypted drives, while low risks involve less sensitive info with shorter encryption keys	
DAY 4-7 5.2 Access Controls	**5.2.A:** Explain how the state or classification of data impacts the type and degree of security applied to that data.	Security depends on whether data is at rest (stored), in transit (moving), or in use (processing) Laws like HIPAA (PHI) and PCI-DSS (payment info) mandate specific storage and handling rules for regulated data	**Scenario 5A: Protecting Sensitive Data**; RBAC, RuBAC, DAC, MAC; Linux terminal or BASH emulator. **Scenario 5A:** Students apply the principle of least privilege to secure a pharmaceutical lab's air-gapped computer. They successfully use the Linux chmod command to set specific read, write, and execute permissions for directories.
	5.2.B: Identify managerial controls related to application and data security.	Managerial controls include Cryptography Policies (defining approved algorithms and key lengths) and Web Application Security Policies (setting timelines for vulnerability remediation)	
	5.2.C: Determine an appropriate access control model to protect applications and data.	Models include Role-Based (RBAC), Rule-Based (RuBAC), Discretionary (DAC), and Mandatory Access Control (MAC) The Bell-LaPadula model (MAC) uses "write up, read down" to protect information	

	5.2.D: Configure access control settings on a Linux-based system.	Students must use the chmod command to set read, write, and execute (rwx) permissions for the owner, group, and others using both numeric and symbolic methods	
DAY 8-10 5.3 Symmetric Cryptography	**5.3.A:** Explain how encryption can be used to protect files.	Cryptography hides plaintext to produce ciphertext. Algorithms are classified as symmetric (one key) or asymmetric (two keys) and may use block or stream encryption methods	**Symmetric Encryption:** OpenSSL tool; Cryptography policies. Students understand the CIA triad of data at rest, in transit, and in use. They use the OpenSSL CLI to encrypt a test file with a 128-bit AES key and then decrypt it using the correct password.
	5.3.B: Apply symmetric encryption algorithms to encrypt and decrypt data.	Advanced Encryption Standard (AES) is the most common symmetric algorithm. Students use tools like OpenSSL to perform encryption and decryption tasks	
DAY 11-13 5.4 Asymmetric Cryptography	**5.4.A:** Determine the appropriate asymmetric key to use when sending or receiving encrypted data.	Asymmetric encryption uses a public key (to encrypt) and a private key (to decrypt) The keys are mathematical inverses, and the security of the system depends on keeping the private key secret	**Scenario 5B: Sending Encrypted Messages**; **Asymmetric Encryption)**; PGP or RSA encryption tools. **Scenario 5B:** Students generate an RSA key pair, share their public key with a partner, and successfully send/receive an encrypted secret message while maintaining private key security.
	5.4.B: Explain why the length of a key impacts the security of encrypted data.	Longer keys increase the keyspace, making it harder for software to guess keys as computational power improves	
	5.4.C Apply asymmetric encryption algorithms to encrypt and decrypt data.	Common algorithms include RSA and Elliptic Curve Cryptography (ECC). Students demonstrate the use of CLI commands to generate key pairs and encrypt/decrypt files	
DAY 14-15 5.5 Secure by Design	**5.5.A:** Identify the application security principles of secure by design and security by default.	Secure by design makes security a core principle in all development phases. Security by default ensures security features are enabled out of the box.	Web application security policies; Input sanitization function examples. Students can evaluate code to ensure companies take ownership of security outcomes. They explain how removing control characters (like ' or --) prevents SQLi and XSS.
	5.5.B: Explain how user input sanitization protects applications.	Programmers must use verification functions to remove malicious characters (like single quotes or semicolons) to prevent SQL injection, XSS, and directory traversal.	
DAY 16-19 5.6 Detecting Data Attacks	**5.6.A:** Explain how to detect attacks on data.	Analysis of accounting logs can reveal unusual file access patterns. Defenders can use honeypots (fake files containing fake PII) or cryptographic hashes to detect if data has been unexpectedly altered	**Honeypots and DLP services**; Windows PowerShell or BASH for hashing; Log entries from Source 4. Students analyze web application and server logs to identify indicators of compromise (IoCs), such as <script> tags for XSS or OR 1=1 for SQLi. They verify file integrity by comparing SHA256 hashes.
	5.6.B: Determine controls for detecting attacks against applications or data.	Criteria include cost, the criticality of the data, and regulatory data classification requirements	
	5.6.C: Evaluate the impact of a method for detecting attacks against an application or data.	Automation is required for effective log analysis. Tools like Data Loss Prevention (DLP) and honeypots provide real-time alerts but may produce false negatives if an adversary steals data without altering it.	

	5.6.D: Identify whether a file has been altered by verifying its hash.	Students use CLI commands like Get-FileHash (PowerShell) or sha256sum (BASH) to compare hash outputs over time; a changed hash indicates the file was altered	
	5.6.E: Apply detection techniques to identify and report indicators of application attacks by analyzing log files.	Detection signatures include SQL control words (WHERE, OR 1=1), HTML script tags for XSS, long URL strings for buffer overflows, and ../ sequences for directory traversal	

Course Title:	Content Area:	Grade Level:	Credit (if applicable)
AP Statistics	Mathematics	Gr. 11 & 12	1.0

Course Description:

The AP Statistics course introduces students to the major concepts and tools for formulating questions, collecting and analyzing data, and interpreting results from data. The practices and skills for the course have been aligned to help students understand the statistical problem-solving process based on the American Statistical Association (ASA) recommendations. The content, skills, and assessments in the AP Statistics course focus on exploring data, sampling and experimentation, probability and simulation, and statistical inference. Students use technology, investigations, problem solving, and writing as they build conceptual understanding.

Aligned Core Resources:

Starnes, Darren and Tabor, Josh (2026).
***The Practice of Statistics* (8th ed.).**
BFW Publishers

AP Classroom

Plan

- Teachers may consider the following approaches as they plan their instruction before teaching each unit.
- Review the overview at the start of each unit guide to identify essential questions, conceptual understandings, and skills for each unit.
- Use the Unit at a Glance table to identify related topics that build toward a common understanding, and then plan appropriate pacing for students.

Teach

- Use the topic pages in the unit guides to identify the required content.
- Integrate the content with a skill, considering any appropriate scaffolding.
- Use the available resources, including AP Videos, on the topic pages to bring a variety of assets into the classroom.

Assess

- While teaching each topic, use AP Classroom to assign students topic questions as a way to continuously check student understanding and provide just-in-time feedback.
- At the end of each unit, use AP Classroom to assign students progress checks, as homework or an in-class task.
- Provide question-level feedback to students through answer rationales; provide formative feedback using Reports.
- Create additional practice opportunities using the Question Bank and assign them through AP Classroom

AP Statistics Course Exam & Description (CED)

Connection to the *BPS Vision of the Graduate*

Critical Thinking and Problem Solving & Content Mastery

- Formulating Questions & Problem Solving
- Quantitative Analysis
- Evidence-Based Justification

Information, Media, and Technology Literacy

- Ethical Data & Media Evaluation
- Technology Integration
- Critical Evaluation of Claims

Effective Communication and Collaboration

- Multi-Modal Communication: Students present statistical claims and distributions through written explanations, graphical representations, and oral presentation
- Collaborative Problem Solving

Civic Awareness & Interdisciplinary Connections

- Interdisciplinary Applications: The curriculum connects statistical reasoning to key societal fields

Additional Course Information:
Knowledge/Skill Dependent courses/prerequisites

Prerequisites:

Grade 11 students may take AP Statistics if they are concurrently enrolled in AP Pre-Calculus, and had a grade of 83 or better in Algebra 2 ACC and were recommended by their teacher.

Grade 12 students may take AP Statistics if they had a

Link to *Completed Equity Audit*

AP STATISTICS_Equity Curriculum Review Audit (2026)

grade of 83 or better in Accelerated Algebra 2 and were recommended by their teacher.	

Standard Matrix

Statistical Practices and Skills	Unit 1	Unit 2	Unit 3	Unit 4	Unit 5
Statistical Practice 1: Formulate Questions *Determine an investigative question for a statistical study*					
1.A Determine a valid investigative question that requires a statistical investigation.	X				
Statistical Practice 2: Collect Data *Identify and justify methods for collecting data and conducting statistical inference*					
2.A Identify information to answer a question or solve a problem.	X	X	X	X	
2.B Justify an appropriate method for ethically gathering and representing data.	X				
2.C Identify appropriate statistical inference methods.			X	X	
2.D Identify types of errors and relationships among components in statistical inference methods.			X	X	
2.E Identify the null and alternative hypotheses.			X	X	
Statistical Practice 3: Analyze Data *Construct representations of data and calculate numerical statistical outputs.*					
3.A Construct tabular and graphical representations of data and distributions.	X	X			X
3.B Calculate summary statistics, relative positions of points within a distribution, and predicted responses.	X	X			X
3.C Calculate and estimate expected counts, percentages, probabilities, and intervals.		X	X	X	
3.D Calculate means, standard deviations, and parameters for probability distributions.		X	X	X	
3.E Calculate appropriate statistical inference method results.			X	X	
Statistical Practice 4: Interpret Results *Interpret results and justify conclusions and methods*					
4.A Describe and compare tabular and graphical representations of data, as well as summary statistics.	X	X			X
4.B Justify a claim based on statistical calculations and results.	X	X			X
4.C Describe distributions and compare relative positions of points within a distribution.	X	X			
4.D Interpret statistical calculations and results to assess meaning or a claim.	X	X	X	X	X
4.E Justify the use of a chosen statistical inference method by verifying conditions.			X	X	
4.F Interpret results of statistical inference methods.			X	X	
4.G Justify a claim based on statistical inference method results.			X	X	

Unit Links

AP Statistics

- Unit 1: Exploring One-Variable Data and Collecting Data
- Unit 2: Probability, Random Variables, and Probability
- Unit 3: Inference for Categorical Data: Proportions
- Unit 4: Inference for Quantitative: Means
- Unit 5: Regression Analysis

Unit Title	
Unit 1: Exploring One-Variable Data and Collecting Data	
Relevant Standards: Bold indicates priority	
1.A, 2.A, 2.B, 3.A, 3.B, 4.A, 4.B, 4.C	
Essential Question(s)	**Enduring Understanding(s)**
• What kinds of questions can be answered using data from websites? • What kind of data is collected about me on social media? • What methods should I use to collect the data to conduct future inference procedures?	• Meaningful statistical investigations begin with well-defined questions and appropriate methods of data collection. • The quality of statistical conclusions depends on how data are collected and whether sources of bias are minimized. • Data displays and numerical summaries reveal important characteristics of distributions, including variability. • Statistical results must be interpreted within the context of the study and communicated ethically.
Demonstration of Learning	**Pacing for Unit**

Progress Check 1
• Multiple-choice: ~44 questions
• Free-response: 3 questions
  ○ Question 1: Multi-Focus on Practices 1 and 2
  ○ Question 2: Multi-Focus on Practices 3 and 4
  ○ Question 3: Multi-Focus on Practices 3 and 4
 	
The additional online question bank will be used to create a mid-unit quiz and other checks for understanding throughout the unit.
 	
College Board AP Exam
Section I MCQ Weighting: 20–30%
(Largest unit weighting on the exam)
• Data Collection & Study Design: Distinguishing between observational studies, experiments, and surveys; identifying random sampling methods, sources of bias (nonresponse, undercoverage), and experimental design principles (control groups, randomization, blinding, confounding variables).
• Data Representation & Summaries: Constructing and reading graphical displays (histograms, boxplots, dotplots, bar charts) and calculating summary statistics (mean, median, standard deviation, IQR, percentiles).
• Distribution Analysis: Describing and comparing single quantitative distributions in context using shape, center, spread, and outliers.
 	
See AP Exam Overview for more information
	15 Block Periods
	
	NOTE:
	Midterm & AP Exam Review / Mock Exams - 11 Blocks
	Flexibility/Buffer/Post-AP Exam Project - 6 Blocks

Family Overview (link below)	**Integration of Technology:**
AP Statistics FAMILY MATERIALS	• Use graphing calculators, Desmos, spreadsheets, or statistical software to create histograms, boxplots, dotplots, and bar charts. • Calculate descriptive statistics using technology. • Analyze authentic datasets using technology
Unit-specific Vocabulary	**Aligned Unit Materials, Resources, and Technology (beyond core resources)**
Investigative question Population Sample Spread Variability Outlier	www.mathmedic.com www.desmos.com www.stapplet.com

Census Observational study Experiment Survey Random sampling Bias Sampling frame Variable Categorical variable Quantitative variable Distribution Center	Histogram Boxplot Dotplot Bar chart Mean Median Standard deviation Interquartile range (IQR) Percentile Skewness Association Confounding variable	https://skewthescript.org/

Opportunities for Interdisciplinary Connections:	**Anticipated misconceptions**
• Science: experimental design, measurement error, data collection. • Social Studies: polling, surveys, demographic studies. • Health: public health data and behavioral studies. • Business/Economics: market research and consumer surveys. • English: evaluating claims supported by data.	1. Confusing random sampling with random assignment when determining the scope of inference (generalizability vs. causation). 2. Believing that increasing the sample size can eliminate or correct sources of sampling bias. 3. Treating bar charts (categorical data) and histograms (quantitative data) as interchangeable. 4. Assuming the mean and standard deviation are resistant measures against extreme outliers or skewness. 5. Omitting context or using non-comparative language when describing and comparing distributions.
Connections to Prior Units	**Connections to Future Units**
Students apply algebraic reasoning, graphical analysis, and data interpretation skills developed in previous mathematics courses.	• Provides the foundation for probability models, inference procedures, and regression analysis. • Establishes the language and habits of statistical thinking used throughout the course.

Differentiation through *Universal Design for Learning*

	Engagement	**Representation**	**Action & Expression**
1.A	Conduct a live class poll on a topic with inherent variability (e.g., student reaction times or commute lengths) vs. deterministic facts.	Flowchart contrasting deterministic questions ("How many desks are in the room?") with statistical questions expecting variability.	Draft three valid statistical questions based on a real-world dataset (e.g., consumer reports) and pitch one to a peer team.
2.A	"Data Detective" activity sorting survey questions into categorical vs. quantitative variables (discrete vs. continuous).	Color-coded data table highlighting observational units (rows) and variable types (columns) with visual icons.	Annotate an AP-style prompt to identify the cases, variables, and measurement units using digital annotation tools or highlighters.
2.B	Analyze misleading graphs from media headlines (e.g., truncated Y-axes, distorted pie chart slices) to debate ethical design choices.	Side-by-side visual matrix showing "Misleading vs. Ethical" graphical representations of the same univariate dataset.	Redesign a misleading news graphic into an accurate graph and record an audio reflection explaining the correction.
3.A	"Human Histogram" activity where students physically line up by height or shoe size before translating data to paper/software.	Step-by-step visual creation guides detailing axis scaling, bin width selection, and labeling for dotplots, stemplots, and boxplots.	Construct univariate displays using choice of medium: hand-drawn posters, graphing calculators, or online applets.
3.B	"Sports Analytics Challenge" calculating summary statistics and z-scores to compare athletes across different historical eras.	Formula scaffolding sheets contrasting formulas for mean/standard deviation with 5-number summary and z-score equations.	Create an interactive digital calculator guide or record a screencast walkthrough computing summary statistics and z-scores.
4.A	"Distribution Speed Dating" matching mystery graphs to contextual descriptions using explicit comparative language.	Visual anchor chart for the **SOCS** framework (Shape, Outliers, Center, Spread) emphasizing mandatory comparative conjunctions (*whereas, higher than*).	Write a comparative analysis essay or record an audio podcast evaluating two competing univariate distributions (e.g., test scores of two classes).

4.B	"Mythbusters: Stat Edition" testing claims about data asymmetry or potential outliers using strict mathematical boundaries.	Claim-Evidence-Reasoning (CER) graphic organizer tailored to the outlier boundaries.	Submit a written CER response or video defense verifying whether a specific data value qualifies as a statistical outlier.
4.C	"Where Do You Stand?" interactive line-up placing students along a scaled Normal curve based on assigned z-score/percentile cards.	Multi-layered Normal distribution diagram displaying z-scores, raw values, percentiles, and Empirical Rule percentages simultaneously.	Present an oral or written explanation of relative standing comparing two individuals in different distributions (e.g., SAT vs. ACT percentiles).
4.D	"Lost in Translation" game where students translate calculated summary metrics into plain-English client advisories.	Sentence-stem bank providing standard AP formulaic phrasing for interpreting standard deviation, z-scores, and percentiles in context.	Write an executive summary or record a video briefing interpreting standard deviation as a measure of typical variation for a business client.

Supporting Multilingual/English Learners (*CELP standards*)

	Emerging	Expanding	Bridging
1.A	Select valid statistical questions (those expecting variability) from visual cards; use sentence frames: "*Is '[Question]' statistical? Yes, because [variable] changes.*"	Formulate statistical questions for one-variable data sets using stems: "*What is the typical [measure] of [population]?*"	Draft, evaluate, and refine complex investigative questions that clearly distinguish between population parameters and sample statistics.
2.A	Match data collection terms (*sample, population, census, variable*) to visual icons and simple scenario cards.	Identify population, sample, and variable type (categorical vs. quantitative) from scenario prompts using a graphic organizer.	Analyze study descriptions to identify sampling frames, potential sources of bias (undercoverage, nonresponse), and variable definitions.
2.B	Match sampling method cards (*SRS, Stratified, Cluster, Systematic*) to visual diagrams showing population selection.	Explain why a sampling method is unbiased or biased using paragraph frames ("*This sampling method creates bias because [group] is left out.*").	Evaluate sampling and experimental designs (blocking, blinding) and justify their ethical and statistical validity in formal written arguments.
3.A	Label components (axes, scales, titles) on pre-drawn graphs (dotplots, stemplots, histograms, boxplots) using a visual word bank.	Construct histograms, stemplots, and boxplots from data sets using structured step-by-step checklists and template grids.	Independently construct and display comparative graphical representations (side-by-side boxplots, back-to-back stemplots) using precise scaling.
3.B	Calculate mean, median, IQR, range, and z-scores using a formula reference card with annotated visual variables.	Calculate summary statistics and percentiles, recording work in structured computational templates with step-by-step starters.	Compute and interpret summary statistics, linear transformations, and relative positions (z-scores and percentiles) in contextual tasks.
4.A	Use the **S.O.C.S.** acronym chart (*Shape, Outliers, Center, Spread*) with picture prompts to list basic distribution features.	Describe distributions using S.O.C.S. and explicit comparative words (*higher than, skewed right, similar variability*) with sentence frames.	Write comprehensive, contextual comparative analyses of multi-group distributions incorporating precise statistical terminology.
4.B	Complete fill-in-the-blank claim statements comparing data points to summary statistics (e.g., "*Point X is an outlier because it is greater than...*").	Write structured justifications for claims about data distributions using provided "Claim-Evidence-Reasoning" (CER) writing frames.	Construct rigorous, contextualized arguments justifying claims about data distributions
4.C	Identify shape (symmetric, skewed) and point position (z-score sign/magnitude) using visual distribution overlays.	Describe an individual data point's location relative to the mean/median using comparative sentence frames ("*A z-score of +2.1 means...*").	Interpret percentiles and z-scores in non-standard distributions, comparing relative standings across different quantitative distributions.
4.D	Match computed summary statistics to their visual meanings on a distribution curve.	Interpret standard deviation and IQR in context using sentence templates ("*The typical distance of [variable] from the mean is...*").	Evaluate claims about real-world data by interpreting the contextual meaning of center, variability, and position measures.

Unit Outline

Lesson Sequence	Skills	Learning Objective	Essential Knowledge	AP Activities *(if available)*
Day 1 *1.1* *Introducing*	1.A Determine a valid investigative	1.1.B Determine an investigative	1.1.A.1 A statistical study is a study in which data are collected from a sample to answer an investigative question about a larger population.	

Statistics: What Can We Learn from Data?	question that requires a statistical investigation.	question	1.1.A.2 Statistical studies are necessary when the population is too large or it is too difficult to collect data from every item or individual in the population. 1.1.A.3 A datum (singular form of data) is a piece of information about an item or individual. A collection of data is called a data set. 1.1.A.4 A population consists of all items or individuals of interest. The population size is represented by the symbol N. 1.1.A.5 A sample selected for study is a subset of the population from which data are obtained. The number of items in the sample, called the sample size, is represented by the symbol n. 1.1.A.6 Each component of a statistical study and the resulting calculations can be related to an aspect of the corresponding real-world context from which the components were derived. This identification of a statistical result with the corresponding contextual component is what is meant by "in context."
	2.A Identify information to answer a question or solve a problem.	1.1.A Identify components within a statistical study	1.1.B.1 An investigative question for a specific study should have a defined purpose and should not be changed based on the data analysis or results. 1.1.B.2 An investigative question should be posed so that the required data can be collected and analyzed.
<u>Day 2</u> *1.2* *Variables*	2.A Identify information to answer a question or solve a problem.	1.2.A Identify observational units, variables, parameters, and statistics from a statistical study or data set	1.2.A.1 An observational unit is an item or individual from which a datum is collected. 1.2.A.2 A variable is a characteristic that may change from one observational unit to another. 1.2.A.3 Data collected on numerical and categorical variables measured on observational units, including photographs, sounds, videos, and text can convey meaningful information. 1.2.A.4 A parameter is a numerical attribute or summary of the variable of interest for a population. 1.2.A.5 A statistic is a numerical attribute or summary of the variable of interest for a sample. The value of a statistic from a certain sample is often not equal to the unknown value of the population parameter but may provide the basis for making inferences about the population parameter.
		1.2.B Identify types of variables.	1.2.B.1 A categorical variable, also called a qualitative variable, takes on values that are category names or group labels. 1.2.B.2 A quantitative variable, also called a numerical variable, takes on numerical values for a measured or counted q
		1.2.C Identify types of quantitative variables.	1.2.C.1 A discrete quantitative variable can take on a countable number of values. The number of values may be finite or countably infinite, as with the whole numbers. 1.2.C.2 A continuous quantitative variable can take on an infinite number of possible values within a given interval. The number of values the variable can take on is measurable but not countable. This variable can take on all possible values between any pair of values.

<u>Day 3</u> *1.3* *Tabular Representation and Summary Statistics for One Categorical Variable*	3.A Construct tabular and graphical representations of data and distributions.	1.3.A Construct categorical one-variable tabular	1.3.A.1 A frequency table shows the number of observational units in each category of a categorical variable. 1.3.A.2 A relative frequency table shows the proportion of observational units in each category of a categorical variable.	
	4.A Describe and compare tabular and graphical representations of data, as well as summary statistics.	1.3.B Describe categorical one-variable tabular representations with summary statistics.	1.3.B.1 Percentages, relative frequencies, and ratios all provide the same information as proportions. 1.3.B.2 Counts and relative frequencies of categorical variables reveal information that can be used to justify claims about the variables in context	
<u>Day 4</u> *1.4* *Graphical Representations for One Categorical Variable*	3.A Construct tabular and graphical representations of data and distributions.	1.4.A Construct categorical one-variable graphical representations.	1.4.A.1 Bar charts, also called bar graphs, display frequencies (counts) or relative frequencies (proportions) for the categories of a single categorical variable. Each bar on a bar chart represents a category of the categorical variable of interest. The height or length of each bar corresponds to the frequency or relative frequency of the observational units in each category. 1.4.A.2 Pie charts are used to display frequencies (counts) or relative frequencies (proportions) for categorical data. Each slice on a pie chart represents a category of the categorical variable of interest. The area of each slice, as a fraction of the total area, corresponds to the relative frequency of observational units falling within each category. The sum of the slices' areas together will equal 1, or 100% of the total area.	
	4.A Describe and compare tabular and graphical representations of data, as well as summary statistics.	1.4.C Compare multiple categorical one-variable tabular and graphical representations.	1.4.C.1 Frequency and relative frequency tables, bar charts, and pie charts can be used to compare two or more data sets in t	
	4.B Justify a claim based on statistical calculations and results	1.4.B Justify a claim using categorical one-variable graphical representations.	1.4.B.1 Graphical representations of a categorical variable reveal information that can be used to justify claims about the variable in context.	
<u>Day 5</u> *1.5* *Graphical Representations for One Quantitative Variable*	3.A Construct tabular and graphical representation	1.5.A Construct quantitative one-variable graph	1.5.A.1 Histograms, stem-and-leaf plots, and dotplots provide a visual representation of the distribution of the values of a quantitative variable. These graphs show the frequency or relative frequency of the quantitative variable values or intervals of values and maintain the natural ordering, smallest to largest, of the quantitative variable. 1.5.A.2 A histogram places the observed values of the quantitative variable into ordered intervals, or bins, along the horizontal axis. Each bar represents an interval or bin, and the height of each bar shows the frequency or relative frequency of the observations within that interval. Altering the interval widths, or bin widths, can change the appearance of the histogram. Alternatively, a histogram can be constructed with bins	**Gallery Walk** Have students work in groups of four to construct a dotplot, stem-and-leaf plot, histogram, or boxplot for a set of student-generated data (e.g., time in minutes to get to school). After the gallery walk, discuss what information can be seen more easily in each graph (e.g., box plots can easily show the IQR).

			on the vertical axis with bars appearing horizontally. 1.5.A.3 A stem-and-leaf plot splits each value of the quantitative variable into two parts: a "stem" (the first digit or digits) and a "leaf" (usually the single digit after the stem digit or digits). Both stems and leaves are ordered from smallest to largest. 1.5.A.4 A dotplot represents each value of the quantitative variable by a dot. Each dot is placed above the horizontal or beside the vertical axis corresponding to the value of that observation, with nearly identical values stacked on top of each other.	
Day 6 *1.6* *Descriptions for One Quantitative Variable Distributions*	4.A continued on next page Describe and compare tabular and graphical representations of data, as well as summary statistics.	1.6.A Describe distributions of quantitative one-variable graphical representations.	1.6.A.1 Descriptions of the distribution of one quantitative variable include shape, center, and variability (spread) as well as any unusual features such as outliers, gaps, or clusters in context. 1.6.A.2 The shape of the distribution of one quantitative variable is skewed to the right (positively skewed) if the right tail (toward larger values) is longer than the left. The shape of the distribution is skewed to the left (negatively skewed) if the left tail (toward smaller values) is longer than the right. The shape of the distribution is approximately symmetric if the left half is approximately the mirror image of the right half. 1.6.A.3 Distributions of one quantitative variable with one main peak are called unimodal. Distributions with two prominent peaks are called bimodal. A distribution in which each frequency or each relative frequency is approximately the same with no prominent peaks is approximately uniform. 1.6.A.4 Outliers for one quantitative variable are data points that are unusually small or large relative to the rest of the data. 1.6.A.5 A gap is a region in a distribution between two values in which there are no observed data. 1.6.A.6 Clusters are concentrations of values usually separated by gaps.	
	4.B Justify a claim based on statistical calculations and results.	1.6.B Justify a claim using distributions of quantitative one-variable graph	1.6.B.1 Graphical representations of a quantitative variable may reveal information that can be used to justify claims about the variable in context.	
Day 7 *1.7* *Summary Statistics for One Quantitative Variable*	3.B Calculate summary statistics, relative positions of points within a distribution, and predicted responses.	1.7.A Calculate measures of center and position for quantitative data	1.7.A.1 Two commonly used measures of center in the distribution of a quantitative variable are the mean and median. 1.7.A.2 The mean is the sum of all the values divided by the number of values and can be found with and without using technology. For a sample, the mean is denoted by x-bar: $\bar{x}=\frac{1}{n}\sum_{i=1}^{n}x_i$, where x_i represents the i^{th} data point in the sample and n represents the number of data values in the sample. 1.7.A.3 The median is the middle value when the data set is ordered from smallest to largest and can be found with and without using technology. One common method for determining the median of a data set with an even number of values is to use the mean of the two middle values. A common method for determining the median of a	

			data set with an odd number of values is to use the value in the middle of all the values. 1.7.A.4 In an ordered data set, the smallest value is the minimum value, and the largest value is the maximum value. 1.7.A.5 The first quartile, denoted by Q1, is the median value of the lower half of the ordered data set from the minimum value to the position of the median. Approximately 25% of the values in the data set are less than or equal to Q1. The third quartile, denoted by Q3, is the median value of the upper half of the ordered data set from the position of the median to the maximum value. Approximately 75% of the values in the data set are less than or equal to Q3. The second quartile, Q2, is also the median of the data set. Q1 and Q3 form the boundaries for the middle 50% of values in an ordered data set. 1.7.A.6 The pth percentile is the value that has p% of the data less than or equal to it when the data set is ordered from smallest to largest. The first and third quartiles are the 25th and 75th percentiles, respectively
		1.7.B Calculate measures of variability for quantitative data.	1.7.B.1 Three commonly used measures of variability (or spread) in the distribution of a quantitative variable are the range, interquartile range, and standard deviation. 1.7.B.2 The range is the difference between the maximum data value and the minimum data value. 1.7.B.3 The interquartile range (IQR) is the difference between the third and first quartiles: Q3 −Q1. 1.7.B.4 The standard deviation is a typical deviation of the data values from their mean and can be found with and without using technology. The sample standard deviation is denoted by s and calculated by $s=\sqrt{\frac{1}{n-1}\sum(x_i-\bar{x})^2}$, where x_i is the data value, x is the mean, and n is the number of data values in the sample. The square of the sample standard deviation, s 2 , is called the sample variance.
		1.7.C Calculate different units of measurement for summary statistics.	1.7.C.1 Changing units of measurement affects the values of the calculated statistics.
		1.7.D Calculate outliers for quantitative data.	1.7.D.1 There are many methods for determining potential outliers.
	4.A Describe and compare tabular and graphical representations of data, as well as summary statistics.	1.7.E Compare multiple quantitative one-variable summary statistics	1.7.E.1 Summary statistics can be used to compare features of two or more independent samples, including center, variability, shape, and outliers.
	4.B Justify a claim based on statistical calculations and results	1.7.F Justify the selection of a summary statistic for describing quantitative data.	1.7.F.1 The median and IQR are considered a resistant (or robust) measure of center and measure of variability, respectively, because outliers do not greatly (if at all) affect their values. Because outliers can affect their values greatly, the mean is considered a nonresistant (or non-robust) measure of center, and the range and standard deviation are considered nonresistant (or nonrobust) measures of variability. 1.7.F.2 Summary statistics of a quantitative variable may reveal information that can be used to justify claims about the variable in context

Day 8 *1.8 Graphical Representations of Summary Statistics for One Quantitative Variable*	3.A Construct tabular and graphical representations of data and distributions.	1.8.A Construct quantitative one-variable graphical representations of summary statistics.	1.8.A.1 A five-number summary is made up of the minimum data value, the first quartile (Q1), the median, the third quartile (Q3), and the maximum data value. 1.8.A.2 A boxplot is a graphical representation of the five-number summary (minimum, first quartile, median, third quartile, maximum). The box represents the middle 50% of data, with a line at the median and the ends of the box corresponding to the quartiles. Lines ("whiskers") that represent 25% of the data extend from the first quartile to the minimum and from the third quartile to the maximum. If there are outliers in the data, the whiskers extend to the most extreme data values that are not outliers, and outliers are usually	
	4.A Describe and compare tabular and graphical representations of data, as well as summary statistics.	1.8.B Describe quantitative one-variable graphical representations of summary statistics based on the relationship of the mean and the median.	1.8.B.1 If a distribution is relatively symmetric, then the values of the mean and median are relatively close to each other. If a distribution is skewed right, then the value of the mean is usually larger than the median. If the distribution is skewed left, then the value of the mean is usually smaller than the median.	
Day 9 *1.9 Comparisons of the Distributions for One Quantitative Variable*	3.B Calculate summary statistics, relative positions of points within a distribution, and predicted responses.	1.9.D Calculate z-scores with population parameters.	1.9.D.1 A standardized score measures the number of standard deviations a data value falls above or below the mean. 1.9.D.2 A z-score is calculated as $\frac{x_i - \mu}{\sigma}$, where x_i is the data value, μ is the population mean, and σ is the population standard deviation. A z-score measures how many standard deviations a data value is above (positive z-score) or below (negative z-score) the mean. When the population mean and standard deviation are unknown, the sample mean and standard deviation may be used to determine a z-score	**Match Mine** Create a blank 3×3 grid as a gameboard and nine index cards depicting distributions of differing shapes, center, skewness, clustering, etc. Pair up students and place a folder between the partners so they cannot see each other's boards. Distribute a blank grid and a set of cards to each partner. Student A arranges the cards however they choose on their grid and then describes that arrangement so that Student B can attempt to match it on their own board. When the pair thinks they have correctly made all matches, have them compare their arrangements to see how well they did.
	4.A Describe and compare tabular and graphical representations of data, as well as summary statistics.	1.9.A Compare multiple quantitative one-variable graphical representations.	1.9.A.1 Graphical representations of a quantitative variable can be used to compare important features between two or more distributions of the same quantitative variable. Histograms, back-to-back stem-and-leaf plots, and dotplots may be used to compare center, variability, shape, outliers, clusters, or gaps in two or more distributions. Boxplots may be used to compare center, variability, outliers, and skewness (or symmetry).	
		1.9.B Compare multiple quantitative one-variable graphical representations of summary statistics.	1.9.B.1 A comparison of graphical representations for two or more distributions can include any of the numerical summaries (e.g., mean, standard deviation, etc.	
	4.B Justify a claim based on	1.9.C Justify a claim using multiple		

	statistical calculations and results.	quantitative one-variable graphical representations.		
	4.C Describe distributions and compare relative positions of points within a distribution.	1.9.E Compare z-scores as measures of relative position for distributions.	1.9.E.1 z-scores may be used to compare relative positions of individual values within a distribution or between distributions.	
Day 10	**Mid-Unit Assessment**			
Day 11 *1.10* *The Investigative Question Revisited and Data Collection*	1.A Determine a valid investigative question that requires a statistical investigation.	1.10. A Determine the components of an investigative question within a statistical study.	1.10.A.1 The first component of an investigative question should guide the data collection process and should be phrased in terms of the variable(s) of interest in the study. 1.10.A.2 The second component of an investigative question should guide the data analysis choice. 1.10.A.3 The third component of an investigative question should indicate the type(s) of conclusion(s) applicable from the study. The investigative question should provide the population to which the conclusions will be applicable and, in the case of an experiment that uses random assignment, a cause-and-effect conclusion.	**Odd One Out** After modeling an odd one out example, have students form groups of four and give each student a description of a statistical study. Explain that three of the studies are of the same type (observational or experimental) and one is different. Have students work together in their groups to determine which study is the odd one out and explain why.
	2.A Identify information to answer a question or solve a problem.	1.10.B Identify a census.	1.10.B.1 A census consists of recording information from all items or individuals in a population.	
		1.10.C Identify an experiment	1.10.C.1 An experiment is a study in which a researcher assigns conditions, or treatments, to experimental units to explore an investigative question of interest about the population. 1.10.C.2 The experimental unit is the observational unit to which the treatment is assigned. When experimental units consist of people, they are sometimes referred to as subjects or participants. 1.10.C.3 An explanatory variable, or factor, is a variable whose different categories, or levels, are imposed on the experimental units. The different categories, or levels, of the explanatory variable are called treatments. When there is more than one explanatory variable, the combinations of the categories, or levels, of the explanatory variables are called treatments. 1.10.C.4 A response variable is an outcome measured on each experimental unit after the treatment has been administered.	
		1.10.D Identify an observational study.	1.10.D.1 An observational study is a study where treatments are not imposed. The	

			researcher records the values of the variables of interest in order to explore an investigative question of interest. 1.10.D.2 A prospective study is one in which the observational units of study are selected at a point in time, and data are gathered both at that time and into the future. 1.10.D.3 A retrospective study is one in which the observational units of study are selected at a point in time and data from the past are gathered. 1.10.D.4 A survey is an observational study in which the data are collected from humans using a standard set of questions. 1.10.D.5 A confounding variable in an observational study provides an alternative explanation for the observed relationship between the explanatory and response variables determined in the study, thereby reducing the possibility of concluding a causal relationship between the explanatory and response variables of interest. To be a confounding variable, a variable must be associated with both the explanatory variable and the response variable.	
	2.B Justify an appropriate method for ethically gathering and representing data.	1.10.E Justify the appropriateness of generalizations for a statistical study.	1.10.E.1 A sample is considered random when all observational units in the sample are selected from the population using some type of random mechanism, such as a random number generator. 1.10.E.2 When observational units, or experimental units, in a sample are randomly selected from a population, it is appropriate to make generalizations about the entire population of individuals from which the sample was selected. 1.10.E.3 A sample is not randomly selected when observational units are deliberately chosen or volunteer themselves to be in the sample. 1.10.E.4 When observational units, or experimental units, in a sample are not randomly selected from a population, it is appropriate to make generalizations only about a population of individuals that are similar to those used in the study	
<u>Day 12</u> *1.11* *Random Sampling*	2.A Identify information to answer a question or solve a problem.	1.11.A Identify a sampling method given a description of a study.	1.11.A.1 Sampling without replacement is a sampling strategy in which an observational unit from a population can be selected only once. The observational unit is not returned to the population before subsequent selections of observational units are made, so there is no chance that the observational unit can be selected again. 1.11.A.2	**Password-Style Games** After completing the lessons on sampling and surveying, use the following nine terms in a password-style game: simple random sample, stratified random sample, cluster random sample, systematic

			Sampling with replacement is a sampling strategy in which an observational unit from the population can be selected more than once. The observational unit is returned to the population before subsequent selections of observational units are made, so it is possible that the observational unit could be selected again. 1.11.A.3 In a simple random sample (SRS) of size n, every sample of the size n has the same chance of being selected. This method is the basis for many types of sampling mechanisms. There are several procedures to obtain a simple random sample; for example, using a random number generator or randomly selecting numbered slips of paper. 1.11.A.4 A stratified random sample involves the division of all individuals in a population into non-overlapping groups, called strata, based on one or more shared attributes or characteristics (homogeneous grouping). Within each stratum a simple random sample is selected, and the selected individuals are combined to form one sample. 1.11.A.5 A cluster random sample involves the division of a population into smaller groups, called clusters. Ideally, each cluster mirrors the heterogeneity of the population, with clusters similar to one another. A simple random sample of clusters is selected from the population to form the sample of clusters. Data are collected from all observational units in each of the selected clusters. 1.11.A.6 A systematic random sample is a method in which sample members from a population are selected according to a random starting point and a fixed, periodic interval between successive sampling units.	random sample, bias, voluntary response bias, undercoverage bias, nonresponse bias, and response bias. Pair students and ask one student per pair to sit facing the back of the classroom. Project or write the terms on the board one at a time while the front-facing students give clues to their partners, who try to guess the terms. The winner is the pair that guesses the most terms correctly.
	2.B Justify an appropriate method for ethically gathering and representing data.	1.11.B Justify the appropriateness of a sampling method.	1.11.B.1 Each random sampling method has different characteristics that make it more appropriate for sampling populations depending on the question being investigated.	
<u>Day 13</u> *1.12 Potential Problems with Sampling*	2.A Identify information to answer a question or solve a problem.	1.12. A Identify potential sources of bias in sampling methods.	1.12.A.1 Bias in a sampling method is a systematic error in the sampling procedure that results in a statistic being consistently larger or consistently smaller than the parameter the statistic is used to estimate. 1.12.A.2 Voluntary response bias is a bias that may occur when a sample consists entirely of volunteers. 1.12.A.3 Undercoverage bias may occur when the sampling method fails to include part of the	

			population or a part of the population is less likely to be selected based on the sampling method. 1.12.A.4 Nonresponse bias may occur because of a failure to obtain responses from some individuals chosen to be sampled. The respondents and nonrespondents could differ significantly in ways that are important for the study. 1.12.A.5 Response bias may occur when responses to a survey or measurements of observational units tend to differ from the "true" value in one direction. Examples include questions that are confusing or leading (question wording bias) or self-reported responses. 1.12.A.6 Nonrandom sampling methods (e.g., samples chosen by convenience or voluntary response) introduce potential bias because they do not use random chance to select the individuals.	
<u>Day 14</u> *1.13 Experimental Design*	2.A continued on next page Identify information to answer a question or solve a problem.	1.13.A Identify elements of a well-designed experiment.	1.13.A.1 A well-designed experiment should include the following: • Comparisons of at least two treatment groups, one of which could be a control group • Random assignment of treatments to experimental units • Replication • Direct control of potential extraneous sources of variation in the response 1.13.A.2 A control group is a collection of experimental units that are created for comparison. A control group may be given a treatment different from the treatment of interest to determine if the treatment of interest has an effect (e.g., a treatment with an inactive substance, a placebo, may be given). 1.13.A.3 The placebo effect is the difference between the average response to a placebo and the average response to no treatment. 1.13.A.4 In a single-blind, also called single-masked, experiment, participants do not know which treatment they are receiving, but members of the research team who interact with them know which treatment each participant is receiving, or vice versa. 1.13.A.5 In a double-blind, also called double-masked, experiment, neither the participants nor the members of the research team who interact with them know which treatment each participant is receiving. 1.13.A.6 An extraneous source of variation, also referred to as an extraneous variable, is a variable that is known (or believed) to affect the response but is not an explanatory variable being studied. 1.13.A.7 The purpose of random assignment is to create treatment groups that are as similar as possible with respect to extraneous sources of variation. If random assignment is successful, the respective distributions of each extraneous variable will be approximately the same for all the treatment groups. 1.13.A.8 A confounding variable in an experiment is a variable that is related to the explanatory variable in such a way that it is difficult to determine which variable, explanatory or confounding, is influencing the change in the response variable. However, in a well-designed experiment, the	

			potential for confounding variables is reduced. 1.13.A.9 Replication within an experiment means more than one experimental unit is assigned to each treatment 1.13.A.10 Direct control in an experiment means keeping the settings of certain potential extraneous sources of variation in the response variable the same from experimental unit to experimental unit.
		1.13.B Identify experimental designs.	1.13.B.1 In a completely randomized design, treatments are assigned to experimental units completely at random. Often the number of experimental units assigned to each treatment will be the same, but the sample sizes in each treatment do not have to be the same. 1.13.B.2 A blocking variable is a source of extraneous variation in the response variable. In a randomized block design, the experimental units are first grouped according to similar values of a blocking variable. These groups are called blocks. Units within the same block are homogeneous with respect to the blocking variable. After the blocks are formed, the treatments are randomly assigned to experimental units within each block so that all treatments occur within every block. 1.13.B.3 The purpose of blocking is to separate the variation in the response caused by the blocking variable from the rest of the extraneous variation in the response. Blocking allows for more precise comparisons of the response across the treatments. Within a block, the treatments can be compared without having to worry about variation in the response caused by changes in the blocking variable. 1.13.B.4 A matched pairs design is a randomized block design with only two treatments. Experimental units are arranged in pairs by matching on one or more extraneous sources of variation in the response variable. Each pair receives both treatments by randomly assigning one treatment to one member of the pair and the other treatment to the second member of the pair. Alternatively, each experimental unit may get both treatments while the order of the treatments is randomized.
	2.B Justify an appropriate method for ethically gathering and representing data.	1.13.C Justify the appropriateness of a particular experimental design.	1.13.C.1 One experimental design may be more appropriate than another experimental design based on the goals of the investigative study, the characteristics of the population, and the sample and variables involved.
		1.13.D Justify the appropriateness of the conclusions based on a well-designed experiment.	1.13.D.1 Using random assignment of treatments to experimental units allows for cause-and-effect conclusions between the explanatory and the response variables because the potential for confounding variables is reduced. 1.13.D.2 Depending on the experimental unit, it may be unethical or difficult to randomly select experimental units to participate in an experiment. In that case, the study's experimental units are obtained from volunteers and will represent the population of experimental units similar to those who participated in the study
Day 15	**Unit Test: AP Progress Check 1**		

Unit Title	
Unit 2: Probability, Random Variables, and Probability	
Relevant Standards: Bold indicates priority	
3.A, 3.B, 3.C, 3.D, 4.A, 4.B, 4.C, 4.D	
Essential Question(s)	**Enduring Understanding(s)**
• How might we represent the reading habits of people with and without an electronic reading device to help describe similarities and/or differences between the two groups? • How can the weather be predicted? • Why might the data we collect influence decisions being made?	• Probability provides a framework for quantifying uncertainty and modeling chance behavior. • Random variables and probability distributions describe the long-run behavior of random processes. • Expected value and variability help inform decisions involving risk and uncertainty. • Simulations can be used to investigate and approximate complex probability situations.
Demonstration of Learning	**Pacing for Unit**

Progress Check 2
• Multiple-choice: ~42 questions
• Free-response: 2 questions
  ○ Question 1: Multi-Focus on Practices 3 and 4
  ○ Question 2: Multi-Focus on Practices 3 and 4
 	
The additional online question bank will be used to create a mid-unit quiz and other checks for understanding throughout the unit.
 	
College Board AP Exam
Section I MCQ Weighting: 15–25%
• Probability Rules: Applying rules for complements, unions, intersections, conditional probability, and testing for independence.
• Random Variables & Distributions: Calculating expected values (mean) and standard deviations for discrete random variables.
• Special Distributions: Solving problems involving normal distributions (z-scores, percentiles) and binomial probability models.
• Sampling Distributions: Understanding sampling variability and applying the Central Limit Theorem (CLT) to understand sample behavior.
 	
See AP Exam Overview for more information
	14 Block Periods
	
	NOTE:
	Midterm & AP Exam Review / Mock Exams - 11 Blocks
	Flexibility/Buffer/Post-AP Exam Project - 6 Blocks

Family Overview (link below)	**Integration of Technology:**
AP Statistics FAMILY MATERIALS	• Use graphing calculators, spreadsheets, or simulation software to model random events. • Generate sampling distributions through simulation. • Explore probability distributions graphically and numerically. • Use graphing calculators and Desmos to calculate probabilities and expected values.
Unit-specific Vocabulary	**Aligned Unit Materials, Resources, and Technology (beyond core resources)**
Chance process Probability Simulation Random outcome Sample space Event Probability distribution Expected value Mean of a random variable Variance Standard deviation	www.mathmedic.com www.desmos.com www.stapplet.com https://skewthescript.org/

Complement Independent events Conditional probability Random variable Discrete random variable	Binomial setting Binomial random variable Binomial probability Normal distribution Parameter Statistic

Opportunities for Interdisciplinary Connections:	**Anticipated misconceptions**
• Science: genetics and inheritance probabilities. • Business: risk analysis and expected profit. • Economics: forecasting and decision-making under uncertainty. • Computer Science: simulations and randomization algorithms. • Games and Sports Analytics: modeling outcomes and probabilities.	1. Believing in the "Law of Averages" (Gambler's Fallacy) for independent outcomes. 2. Confusing independent events with mutually exclusive (disjoint) events. 3. Subtracting variances or directly adding standard deviations when combining random variables. 4. Confusing a single sample distribution with a population distribution or a sampling distribution. 5. Misinterpreting the Central Limit Theorem as stating that the population or sample data distribution becomes Normal as sample size increases.
Connections to Prior Units	**Connections to Future Units**
• Builds on concepts of variability and data collection introduced in Unit 1. • Uses distributions and graphical interpretation skills developed in Unit 1.	• Provides the theoretical foundation for statistical inference. • Supports understanding of sampling distributions, confidence intervals, and hypothesis testing. • Introduces concepts used in regression inference.

Differentiation through *Universal Design for Learning*

	Engagement	**Representation**	**Action & Expression**
2.A	Investigate bivariate relationships in popular culture (e.g., screen time vs. sleep duration) to formulate explanatory/response questions.	Matrix mapping bivariate questions to variable types (Quantitative vs. Quantitative; Categorical vs. Quantitative).	Write two bivariate investigative questions for a self-selected real-world dataset and justify why they require two-variable analysis.
3.A	"Variable Match" challenge identifying explanatory (X) and response (Y) variables in real-world studies (e.g., study time vs. exam score).	Color-coded scatterplot axes diagram identifying independent variable (X-axis) and dependent variable (Y-axis).	Construct a bivariate variable map identifying lurking variables that could influence bivariate relationships.
3.B	Evaluate real-world scatterplots where improper extrapolation led to faulty public policy or business decisions.	Visual guide highlighting the dangers of extrapolation beyond the range of observed X-data.	Write an ethical evaluation report assessing whether a linear model can be legitimately applied to a specific prediction scenario.
3.C	"Bivariate Graph Off" creating scatterplots, residual plots, two-way tables, and segmented bar charts from live class data.	Step-by-step visual checklist for scatterplot construction (scaling, plotting points, drawing Least-Squares Regression Lines (**LSRL**).	Generate scatterplots and residual plots using choice of technology (TI-84, Desmos, R, or Python) or physical graphing tools.
3.D	"Predict the Future" lab calculating LSRL equations to predict outcomes (e.g., predicting movie revenue from budget).	Dual-column reference chart comparing manual slope/intercept formulas with computer software regression outputs.	Solve prediction problems by submitting worked calculations, annotated calculator screenshots, or recorded video demonstrations.
4.B	"Scatterplot Sorting Game" categorizing bivariate graphs by Direction, Unusual features, Form, and Strength (**DUFS**).	Anchor chart breaking down the **DUFS** acronym with visual examples of linear/nonlinear forms and varying correlation strengths.	Deliver an audio recording or written essay describing the relationship in a scatterplot using contextual DUFS terminology.
4.D	"Residual Detective" evaluating residual plots to determine if a linear model is appropriate for a given dataset.	Side-by-side visual comparison showing a random residual scatter (linear appropriate) vs. a curved residual pattern (linear inappropriate).	Write a formal justification argument verifying or refuting model linearity based on residual plot patterns and r^2 values.

Supporting Multilingual/English Learners (CELP standards)			
	Emerging	**Expanding**	**Bridging**
2.A	Identify given probabilities from a word problem using a color-coded text highlighter guide.	Extract conditional probability statements and random variable parameters from word problems using a structured probability organizer.	Parse complex conditional and independent probability scenarios, identifying underlying probability distributions (Binomial vs. Geometric).
3.A	Complete blank 2-way tables, Venn diagrams, or probability distribution tables using simple addition/subtraction prompts.	Construct tree diagrams, Venn diagrams, and probability distribution histograms from scenario prompts using guided templates.	Construct complex two-way tables, tree diagrams, and discrete/continuous probability density functions for multi-step random variables.
3.B	Calculate simple probabilities using visual counting cards.	Calculate expected value and standard deviation of discrete random variables using guided formula sheets.	Compute linear combinations of random variables and normal distribution proportions.
3.C	Calculate basic probabilities using addition and multiplication formulas with color-coded key charts.	Calculate conditional probabilities and binomial/geometric probabilities using formula templates or calculator guides.	Calculate complex joint, conditional, binomial, geometric, and normal distribution probabilities across multi-step scenarios.
3.D	Identify formulas for Binomial mean and standard deviation on an annotated formula card.	Calculate parameters for binomial and geometric random variables using structured computational guides.	Calculate and transform parameters for combinations and transformations of random variables, justifying variance additions.
4.B	Match probability calculation results to visual "Likely / Unlikely" decision cards.	Justify whether two events are independent or mutually exclusive using structured mathematical proof templates.	Formulate logical arguments assessing whether an observed event is statistically unusual based on calculated probability distributions.
4.D	Identify whether calculated expected values represent long-run averages using true/false sentence strips.	Interpret expected value and standard deviation of a random variable in context using sentence frames (*"Over many trials, the average..."*).	Critically interpret expected value, variance, and probability outcomes in real-world risk, insurance, and decision-making contexts.

Unit Outline

Lesson Sequence	Skills	Learning Objective	Essential Knowledge	AP Activities *(if available)*
Day 1 *2.1 Tabular and Graphical Representations for the Distributions of Two Categorical Variables*	4.A Describe and compare tabular and graphical representations of data, as well as summary statistics.	2.1.A Compare tabular and graphical representations for the relationship between two categorical variables.	2.1.A.1 A two-way table, also called a contingency table, can be used to summarize and compare data for two categorical variables. The entries in the cells of the table can be frequencies (i.e., counts) or relative frequencies (i.e., proportions). 2.1.A.2 Side-by-side bar charts, segmented bar charts, and mosaic plots are examples of graphs used to display the relationship between two categorical variables. In these graphs, the frequency or relative frequency of each category, or level, of one of the categorical variables is displayed for each category of the other categorical variable. 2.1.A.3 Graphical representations of two categorical variables can be used to compare the relationship of one categorical variable across the levels of the other categorical variable and determine whether the two variables are associated.	**Quiz-Quiz-Trade** Give students a card containing a question with a two-way table and have them write the answer on the back. Then have them stand up and find a partner. One student quizzes the other, and then they reverse roles. Have them switch cards, find a new partner, and repeat the process.
	4.B Justify a claim based on statistical	2.1.B Justify a claim using tabular and graphical	2.1.B.1 Tabular and graphical representations for the distributions of two categorical variables may reveal information that can be used to justify	

	calculations and results.	representations for the distributions of two categorical variables	claims about the variable in context.	
Day 2 Part 1 *2.2 Summary Statistics for Two Categorical Variables*	3.B Calculate summary statistics, relative positions of points within a distribution, , and predicted responses.	2.2.A Calculate summary statistics from two-way tables.	2.2.A.1 A joint relative frequency in a two-way table is a cell frequency divided by the total for the entire table. 2.2.A.2 A marginal relative frequency in a two-way table is a row total divided by the total for the entire table or a column total divided by the total for the entire table. 2.2.A.3 A conditional relative frequency is a relative frequency computed by restricting to a particular level, or category of interest. A conditional relative frequency can be a cell frequency in a row divided by the total for that row or it can be a cell frequency in a column divided by the total for that column.	
	4.A Describe and compare tabular and graphical representations of data, as well as summary statistics.	2.2.B Compare summary statistics for two categorical variables.	2.2.B.1 Summary statistics for two categorical variables can be used to compare distributions for evidence of association between the two variables.	
	4.B Justify a claim based on statistical calculations and results.	2.2.C Justify a claim using summary statistics for two categorical variables.	2.2.C.1 Summary statistics for two categorical variables may reveal information that can be used to justify claims about the variables in context.	
Day 2 Part 2 *2.3 Estimating Probabilities Using Simulation*	3.C Calculate and estimate expected counts, percentages, probabilities, and intervals.	2.3.A Estimate probabilities using simulations.	2.3.A.1 A random process generates results that are determined by chance. 2.3.A.2 An outcome is the result of one trial of a random process. 2.3.A.3 An event is a collection of outcomes. 2.3.A.4 Simulation is a way to model random events such that simulated outcomes closely match real-world outcomes. All possible outcomes are associated with a value to be determined by chance. Record the counts of simulated outcomes and the count total. 2.3.A.5 The probability of an outcome or event is its long-run relative frequency—that is, its relative frequency over a large number of trials. 2.3.A.6 The relative frequency of an outcome or event determined from empirical data can be used to estimate the actual, or true, probability of that outcome or event. 2.3.A.7 The law of large numbers states that for independent trials, as the number of trials increases, the long-run relative frequency of the outcome or event gets closer and closer to a single value.	
Day 3 *2.4 Introduction to Probability*	3.C Calculate and estimate expected	2.4.A Calculate probabilities for events and	2.4.A.1 The sample space of a random process is the set of all possible nonoverlapping outcomes. The probability of the sample space is 1.	**Think-Pair-Share** Provide students with a set of five probability questions: one for each of the

	counts, percentages, probabilities, and intervals.	their complements.	2.4.A.2 If all outcomes in the sample space are equally likely, then the theoretical probability an event E will occur is $\frac{\text{number of outcomes in event } E}{\text{total number of outcomes in the sample space}}$ The probability of event E occurring is written as P(E) . 2.4.A.3 The probability of an event is a number between 0 and 1, inclusive. 2.4.A.4 The probability of the complement of an event E, which can be written as E', $\overline{E}$, or E^C (i.e., the probability of "not E") is equal to 1- P(E).	complement rule, a mutually exclusive event, a conditional probability, the general multiplication rule, and an independent event. Ask students to individually identify the formula needed to solve each problem without doing the final calculations. Then have them share their thoughts with a partner.
Day 4 *2.5 Mutually Exclusive Events*	4.B Justify a claim based on statistical calculations and results.	2.5.A Justify why two events are mutually exclusive (or disjoint) using joint probability.	2.5.A.1 The probability that events A and B both will occur, sometimes called the joint probability, is the probability of the intersection of A and B. Joint probability is defined as P (A intersect B) or P (A ∩ B). 2.5.A.2 Two events are mutually exclusive, or disjoint, if they cannot occur at the same time. This means that if two events are mutually exclusive, then P (A ∩ B) = 0.	
Day 5 *2.6 Conditional Probability*	3.C Calculate and estimate expected counts, percentages, probabilities, and intervals.	2.6.A Calculate conditional probabilities.	2.6.A.1 The probability that event A will occur given that event B has occurred is called a conditional probability and is written as P(A|B). Conditional probability is defined as $P(A \mid B) = \frac{P(A \cap B)}{P(B)}.$ 2.6.A.2 The general multiplication rule states that the probability that events A and B both will occur is equal to the probability that event A will occur multiplied by the conditional probability that event B will occur given that event A has occurred. The multiplication rule is defined as $P(A \cap B) = P(A) \cdot P(B \mid A)$	
Day 6 *2.7 Independent Events and Unions of Events*	3.C Calculate and estimate expected counts, percentages, probabilities, and intervals.	2.7.A Calculate probabilities for independent events and for the union of two events	2.7.A.1 Events A and B are independent if and only if knowing whether event A has occurred (or will occur) does not change the probability that event B will occur. When events A and B are independent, then P(A|B) = P(A), P(B|A) = P(B), and P (A ∩ B) = P(A)● P(B). 2.7.A.2 The probability that event A or event B (or both) will occur is the probability of A union B. The probability of the union is defined as P (A ∪ B). 2.7.A.3 P (A union B) = P (A) + P(B) - P(A intersect B) , or P (A ∪ B) = P(A) +P(B) - P(A ∩ B).	
Day 7	**Mid-Unit Assessment**			

Day 8 *2.8* *Introduction to Random Variables and Probability Distributions*	3.A Construct tabular and graphical representations of data and distributions.	2.8.A Construct a probability distribution for a discrete random variable.	2.8.A.1 A random variable is a variable whose values have numerical outcomes that result from a random phenomenon. 2.8.A.2 A probability distribution for a discrete random variable shows the probability associated with every possible value of the random variable. The sum of the probabilities over all possible values of a discrete random variable is 1. 2.8.A.3 A discrete probability distribution can be determined using the rules of probability or estimated with a simulation. 2.8.A.4 A discrete probability distribution can be represented as a graph, table, or function showing the probabilities associated with values of a random variable. 2.8.A.5 A cumulative probability distribution can be represented as a table or function and shows the probability of being less than or equal to each value of the discrete random variable.	
Day 9 *2.9* *Parameters of Random Variables*	3.B Calculate summary statistics, relative positions of points within a distribution, and predicted responses.	2.9.A Calculate the mean and standard deviation for a discrete random variable.	2.9.A.1 A numerical value measuring a characteristic of a probability distribution of a random variable, or a population, is a parameter. The value of a parameter is a single, fixed value. 2.9.A.2 The expected value (or mean) of a probability distribution is a parameter and is denoted by $E(X)$ or μ_X. For a discrete random variable X, the expected value is calculated as $\mu_X = \sum x_i \cdot P(x_i)$ where x_i is the possible value of the random variable and $P(x_i)$ is the probability of the possible value of the random variable. The expected value can be interpreted as the long-run average outcome of the random variable. The discrete random variable can only take on values that are countable or finite. 2.9.A.3 The standard deviation of a probability distribution is a parameter represented by $SD(X)$ or σ_X. For a discrete random variable X, the standard deviation is calculated as $\sigma_X = \sqrt{\sum (x_i - \mu_X)^2 \cdot P(x_i)}$ where x_i is the possible value of the random variable, μ_X is the mean, and $P(x_i)$ is the probability of the possible value of the random variable. The standard deviation can be interpreted as the typical deviation of the values of the random variable from the mean value (or expected value) of the random variable over the long run. The square of the standard deviation of a random variable is called the variance of the random variable and is denoted as $V(X)$ or σ_X^2.	
	4.D Interpret statistical calculations and results to assess meaning or a claim.	2.9.B Interpret the mean and standard deviation for a discrete random variable.	2.9.B.1 The mean and standard deviation for the probability distribution of a discrete random variable should be interpreted in the context of a specific population.	
Day 10 *2.10* *The Binomial Distribution*	4.B Justify a claim based on statistical calculations and results.	2.10.A Justify why a random variable is or is not a binomial random variable.	2.10.A.1 A binomial random variable, X, is a discrete random variable that counts the number of successes in repeated independent trials, n, that have only two possible outcomes (success or failure), with the probability of success p and the probability of failure 1− p.	**Predict and Confirm** Before performing a class simulation, have students discuss with their neighbor what values the distribution may take and how often they expect/predict those values to occur. For instance, what might the
	3.D Calculate	2.10.B Calculate the	2.10.B.1	

	means, standard deviations, and parameters for probability distributions.	mean and standard deviation for a binomial distribution.	If a random variable is binomial, its mean, μ_X, is *np* and its standard deviation, σ_X, is $\sqrt{np(1-p)}$.	distribution look like for a binomial setting with p = 05. and n =16 when we perform 20 trials? Have students perform the simulation and compare the results to their predictions.
	4.D Interpret statistical calculations and results to assess meaning or a claim.	2.10.C Interpret the mean, standard deviation, and probabilities for a binomial distribution.	2.10.C.1 The mean, standard deviation, and probabilities for a binomial distribution should be interpreted in context.	
	3.C Calculate and estimate expected counts, percentages, probabilities, and intervals.	2.10.D Estimate probabilities of binomial random variables using data from a simulation.	2.10.D.1 A probability distribution can be constructed using the rules of probability or estimated with a simulation.	
		2.10.E Calculate probabilities for a binomial distribution.	2.10.E.1 The probability that a binomial random variable, X, has exactly *x* successes for *n* independent trials, when the probability of success is *p*, is calculated as $P(X=x)=\binom{n}{x}p^x(1-p)^{n-x}$, . *x* = 0, 1,2,...*n* This is called the binomial probability function.	
Day 11-12 *2.11* *The Normal Distribution*	4.C Describe distributions and compare relative positions of points within a distribution.	2.11.A Describe a normal distribution.	2.11.A.1 A continuous random variable is a variable that can take on any value within a specified domain. Every interval within the domain has a probability associated with it. 2.11.A.2 Many continuous random variables are wellmodeled by a normal distribution. 2.11.A.3 A normal distribution can be described as a continuous, unimodal, bell-shaped, and symmetric curve. 2.11.A.4 A normal curve can be used to model a distribution of data and a continuous random variable. 2.11.A.5 The normal distribution, or the normal curve, is identified by two parameters, the mean, μ, and the standard deviation, σ . The smaller the standard deviation, the taller and more concentrated the normal curve is around its mean. The larger the standard deviation, the shorter and less concentrated the normal curve is around its mean.	**Reversing Interpretations** Give pairs of students four pictures of normal distributions with various parts shaded. Have students create the question that could have resulted in the picture shown. For example, if a value of 15 is labeled and the distribution is shaded to the right of 15, students could write, "What is the probability that a value is more than 15?"
	3.D Calculate means, standard deviations, and parameters for probability	2.11.B Calculate the mean and standard deviation for a normal distribution	2.11.B.1 A standard normal distribution is a normal distribution with mean μ = 0 and standard deviation σ =1.	

	distributions.			
	3.C Calculate and estimate expected counts, percentages, probabilities, and intervals.	2.11.C Calculate percentages from a normal distribution using the empirical rule.	2.11.C.1 The empirical rule can be used to estimate the area of a region under the graph of the normal distribution curve. For a normal distribution, approximately 68% of observations are within 1 standard deviation of the mean, approximately 95% of observations are within 2 standard deviations of the mean, and approximately 99.7% of observations are within 3 standard deviations of the mean. This is called the empirical rule, or the 68–95–99.7 rule.	
		2.11.D Calculate the probability that a particular value lies within a given interval of a normal distribution.	2.11.D.1 If the distribution of a random variable is approximately normal, the probability that the random variable takes on values within a particular interval of the random variable is determined by the area under the normal curve within that interval. The total probability or area under the normal curve is 1.	
		2.11.E Calculate the associated intervals and areas of a normal distribution.	2.11.E.1 The boundaries of an interval associated with a given area in a normal distribution can be determined using technology or using z-scores and a standard normal table. 2.11.E.2 Intervals associated with a given area in a normal distribution can be determined by assigning appropriate inequalities to the boundaries of the intervals. To determine the intervals, p is defined as a number between 0 and 100, x_a is the lower bound, and x_b is the upper bound on a normal distribution. 2.11.E.2.i $P(X < x_a) = \frac{p}{100}$ means that the lowest p% of the values lie to the left of x_a. 2.11.E.2.ii $P(x_a < X < x_b) = \frac{p}{100}$ means that p% of the values lie between x_a and x_b. 2.11.E.2.iii $P(X > x_b) = \frac{p}{100}$ means that the highest p% of the values lie to the right of x_b. 2.11.E.2.iv To determine the most extreme p% of values on both sides requires dividing the area associated with p% into two equal areas on either extreme of the distribution: $P(X < x_a) = \frac{1}{2}\left(\frac{p}{100}\right)$ and $P(X > x_b) = \frac{1}{2}\left(\frac{p}{100}\right)$ mean that half of the p% most extreme values lie to the left of x_a and half of the p% most extreme values lie to the right of x_b.	
	4.C Describe	2.11.F Compare	2.11.F.1 Percentiles and proportions may be used to	

	distributions and compare relative positions of points within a distribution.	measures of relative position for distributions.	compare relative positions of individual values within a normal distribution or between normal distributions.	
Day 13 *2.12 Sampling Distributions and the Central Limit Theorem*	4.C Describe distributions and compare relative positions of points within a distribution	2.12.A Describe sampling distributions with simulations	2.12.A.1 A sampling distribution of a statistic is the distribution of values of the statistic for all possible samples of a given size from a given population. 2.12.A.2 The sampling distribution of a statistic can be simulated by repeatedly generating a large number of random samples from the population assuming known value(s) for the parameter(s). The value of the statistic is determined and recorded for each sample. The resulting distribution of the sample statistic values approximates the sampling distribution of the statistic. 2.12.A.3 A randomization distribution is the distribution of a statistic generated by simulation from repeatedly randomly reallocating, or reassigning, the response values to treatment groups. The value of the statistic is determined and recorded for each reallocation, or reassignment. The resulting distribution of the statistic values approximates the sampling distribution of the statistic. 2.12.A.4 The central limit theorem (CLT) states that the sampling distribution of a mean of a random sample has a shape that can be approximated by a normal distribution. The larger the sample is, the better the approximation will be.	
Day 14	**Unit Test: AP Progress Check 2**			

Unit Title
Unit 3: Inference for Categorical Data: Proportions
Relevant Standards: Bold indicates priority
2.C, 2.D, 2.E, 3.C, 3.D, 3.E, 4.B, 4.C, 4.D, 4.E, 4.F, 4.G

Essential Question(s)	Enduring Understanding(s)
• How can we measure changing opinions in populations over time? • When can we perform inference calculations using data from websites to answer everyday questions? • How can we determine whether the difference between two groups is statistically significant? • Are the distributions of various types of wild birds different in urban areas than in rural areas?	• Sample results vary naturally, and statistical inference accounts for this variability. • Confidence intervals provide plausible estimates of population proportions. • Hypothesis tests evaluate claims about population proportions using evidence from sample data. • Statistical conclusions should consider both statistical significance and practical importance.
Demonstration of Learning	**Pacing for Unit**

Progress Check 3
• Multiple-choice: ~65 questions
• Free-response: 3 questions
  ○ Question 1: Inference
  ○ Question 2: Inference
  ○ Question 3: Inference
 	
The additional online question bank will be used to create a mid-unit quiz and other checks for understanding throughout the unit.
 	
College Board AP Exam
Section I MCQ Weighting: 15–25%
• Point Estimators & Sampling Distributions: Estimating population parameters using sample proportions.
• Proportion Inference Procedures: Constructing and interpreting 1-proportion and 2-proportion z-confidence intervals and hypothesis tests.
• Chi-Square Procedures: Conducting Chi-Square tests for homogeneity and independence to analyze categorical relationships across two-way tables.
• Reasoning & Conditions: Verifying random sampling and Large Counts conditions, calculating test statistics/p-values, and drawing contextual conclusions.
 	
See AP Exam Overview for more information
	18 Block Periods
	
	NOTE:
	Midterm & AP Exam Review / Mock Exams - 11 Blocks
	Flexibility/Buffer/Post-AP Exam Project - 6 Blocks

Family Overview (link below)	**Integration of Technology:**
AP Statistics FAMILY MATERIALS	• Construct confidence intervals for proportions using a graphing calculator or Desmos.. • Perform one- and two-sample z-tests for proportions using a graphing calculator or Desmos. • Interpret calculator and software output..
Unit-specific Vocabulary	**Aligned Unit Materials, Resources, and Technology (beyond core resources)**
Sampling distribution Statistic Parameter Point estimate Alternative hypothesis P-value Statistical significance Practical significance	www.mathmedic.com www.desmos.com www.stapplet.com https://skewthescript.org/

Margin of error	Type I error
Confidence interval	Type II error
Confidence level	Power
Standard error	One-proportion z-interval
Inference	One-proportion z-test
Hypothesis test	Two-proportion z-interval
Null hypothesis	Two-proportion z-test

Opportunities for Interdisciplinary Connections:	**Anticipated misconceptions**
• Political Science: election polling. • Public Health: vaccination and treatment studies. • Sociology: opinion surveys and demographic comparisons. • Psychology: behavioral research. • Journalism: interpretation of polling data.	1. Misinterpreting a confidence interval as the probability that individual data values or a parameter fall into a specific calculated interval. 2. Stating that a high p-value proves or "accepts" the null hypothesis. 3. Mixing up when to use pooled versus unpooled standard errors in two-proportion inference procedures. 4. Believing that Type I error probability (\alpha) and Type II error probability add up to 1. 5. Confusing Chi-Square tests of Homogeneity with Chi-Square tests of Independence.
Connections to Prior Units	**Connections to Future Units**
• Uses probability models and sampling variability from Unit 2. • Applies principles of data collection and study design from Unit 1.	Establishes the framework for all subsequent inference procedures.Introduces confidence intervals, hypothesis testing, and error analysis used again with means and regression.

Differentiation through *Universal Design for Learning*

	Engagement	Representation	Action & Expression
2.C	"Simulation Showdown" comparing physical card-shuffling re-randomization tests with computer applet simulations to evaluate experimental chance variation.	Flowchart decision tree mapping study design (Random Assignment vs. Random Selection) to the appropriate simulation-based inference technique (permutation test vs. bootstrap resampling).	Build an interactive flowchart or record an audio walkthrough explaining why a re-randomization simulation is chosen over a standard observational survey model for an experiment.
2.D	"False Discovery Lab" simulating drug trials where the treatment has zero effect to observe how often random assignment chance leads to a false positive result (Type I error).	Visual 2x2 matrix (True Effect vs. Study Decision) overlaid with levers showing how increasing sample size n or reducing assignment variation reduces false negative risks (Type II error).	Construct an infographic or record a video reflection explaining how small sample sizes in experimental designs increase the risk of Type II errors.
2.E	"By Chance Alone?" challenge formulating hypotheses for famous experiments (e.g., "Lady Tasting Tea") testing whether results could happen purely by random assignment chance.	Sentence-template guide mapping experimental claims to symbolic and verbal null/alternative forms (H0: Treatment has no effect / difference is due to chance; Ha: Treatment causes a genuine difference).	Write verbal and symbolic H0 and Ha for three experimental scenarios and record an audio explanation defining the parameters/treatment effects in context.
3.C.	"Card Shuffling / Applet Lab" performing 100+ simulated re-randomizations of experimental data and counting how many yield a treatment difference as extreme as observed.	Visual dotplot of a simulation distribution with the observed experimental result highlighted and the tail area shaded to display the estimated p-value.	Estimate p-values from simulation dotplots using choice of tool (applet, manual tally, or Python script) and submit annotated calculation logs.
3.E	"Difference in Means / Proportions Lab" calculating the observed test statistic from raw experimental group data prior to running simulations.	Worked example cards showing step-by-step subtraction of treatment group means/proportions alongside computer applet input fields.	Submit a calculation portfolio featuring both hand-calculated group statistic differences and applet-generated simulation test statistics.
4.E	"Scope of Inference Auditor" auditing study scenarios to verify whether Random Assignment was used	2x2 Scope of Inference Grid paired with a condition checklist (Random	Produce an "Experimental Design Audit Report" verifying whether study

	(allowing causal inference) and whether Random Selection was used (allowing population generalization).	Assignment, Independent Allocation, Sufficient Simulation Trials \ge 1000).	conditions justify making a causal claim via simulation-based inference.
4.F	"Translate the Simulation" converting raw simulation p-values into plain-English statements about the probability of getting observed experimental differences by chance alone.	Fill-in-the-blank template for AP-style simulation interpretations: *"Assuming [treatment has no effect], the probability of getting a difference in [statistic] of [value] or greater purely due to random assignment chance is [p-value]."*	Record a video or podcast segment explaining what a simulation-based p-value means to an audience reviewing a clinical trial result.
4.G	"Jury Verdict: Causation vs. Chance" evaluating simulation p-values against a threshold (\alpha = 0.05) to declare whether an experimental treatment genuinely works or if results are inconclusive.	Decision tree linking p-value threshold to the final claim: *"Because p-value is small, we have convincing evidence that [treatment causes effect]."*	Write a complete CER justification essay or deliver a mock courtroom closing argument stating whether an experiment proves causation and specifying the target population.

Supporting Multilingual/English Learners (*CELP standards*)

	Emerging	Expanding	Bridging
2.C	Match categorical inference problem cards to method names using a visual flow chart.	Identify the correct categorical inference procedure from scenario prompts using a decision-tree graphic organizer.	Discriminate between 1-prop, 2-prop, χ^2 goodness-of-fit, χ^2independence, and χ^2 homogeneity tests across ambiguous real-world research contexts.
2.D	Match *Type I Error*, *Type II Error*, and *Power* to visual scenarios using a decision truth-table card.	Describe Type I/II errors and Power in context using structured scenario frames	Analyze trade-offs between α, β,, sample size n, and effect size, explaining relationships in formal written evaluations.
2.E	Select correct null and alternative hypothesis statements using parameter symbol cards.	Write H_0 and H_a hypotheses for proportions in symbols and words using structured sentence frames	Formulate parameter definitions and hypotheses for 1-proportion, 2-proportion, and χ^2 tests with non-directional or directional claims.
3.C.	Calculate expected counts for χ^2 tests using the formula with color-coded table templates.	Calculate standard errors, margins of error, and confidence intervals for proportions using annotated formula guides.	Compute confidence intervals, test statistics, p-values, and χ^2 expected counts across single-sample and two-sample tasks.
3.E	Identify the test statistic and p-value from a calculator/software output screenshot using highlighter pens.	Calculate z-test statistics and corresponding p-values for proportions using structured step-by-step formula worksheets.	Independently execute full computational procedures for 1-prop, 2-prop, and χ^2 inference tests using technology and formula mechanics.
4.E	Check off verified conditions (*Random, 10% condition, Large Counts)* on a visual condition checklist.	Verify and write out conditions for proportion inference methods using structured paragraph stems.	Evaluate and justify inference conditions (including expected cell counts > 5 for χ^2, addressing minor violations in context.
4.F	Interpret confidence intervals using a fill-in template: *"We are [95]% confident that the true proportion of [context] is between [L] and [U]."*	Interpret confidence intervals and p-values in context using complete sentence starters	Interpret confidence levels, p-values, and χ^2 components in context, explaining the practical meaning of statistical significance.
4.G	Match p-value decisions (reject or fail to reject) using visual rule cards.	Write formal conclusions for hypothesis tests using decision templates	Construct rigorous, contextualized statistical arguments justifying claims about population proportions based on confidence intervals or hypothesis test results.

Unit Outline

Lesson Sequence	Skills	Learning Objective	Essential Knowledge	AP Activities *(if available)*
Day 1 *3.1* *Estimators*	4.B Justify a claim based on statistical	3.1.A Justify why an estimator is or is not	3.1.A.1	

	calculations and results.	unbiased.	When estimating a population parameter, an estimator is unbiased if, on average, the value of the estimator does not underestimate or overestimate the population parameter.
	3.D Calculate means, standard deviations, and parameters for probability distributions.	3.1.B Calculate estimates for a population parameter.	3.1.B.1 A sample statistic is a point estimator of the corresponding population parameter and can be thought of as the estimate of the population parameter. For example, the sample proportion p is a point estimator for the population proportion p.
Day 2 *3.2 Sampling Distributions for Sample Proportions*	3.D Calculate means, standard deviations, and parameters for probability distributions.	3.2.A Calculate the mean and standard deviation of a sampling distribution for a sample proportion.	3.2.A.1 For a population with population proportion p, when the sampled values are independent, the sampling distribution of a sample proportion $\hat{p}$ has a mean $\mu_{\hat{p}} = p$ and a standard deviation $\sigma_{\hat{p}} = \sqrt{\frac{p(1-p)}{n}}$.
	4.E Justify the use of a chosen statistical inference method by verifying conditions.	3.2.B Justify the appropriateness of conditions for the sampling distribution of a sample proportion.	3.2.B.1 Sampling without replacement requires that two conditions be met: 3.2.B.1.i The randomization condition—the data should be collected using a random sample. 3.2.B.1.ii The 10% condition—the population size must be at least 10 times larger than the sample size $(n \le 10\%N)$, where N is the size of the population and n is the sample size. 3.2.B.2 The sampling distribution of the sample proportion p is approximately normal provided the sample size is large enough. To ensure the sample size is large enough, the following condition must be met: $np \ge 10$ and $n(1-p) \ge 10$, where *np* is the expected number of successes and $n(1-p)$ is the expected number of failures.
	4.D Interpret statistical calculations and results to assess meaning or a claim.	3.2.C Interpret the mean, standard deviation, and probabilities for a sampling distribution of a sample proportion.	3.2.C.1 The mean, standard deviation, and probabilities for a sampling distribution of a sample proportion should be interpreted in the context of a specific population.
Day 3 *3.3 Constructing a Confidence Interval for a Population Proportion*	2.C Identify appropriate statistical inference methods.	3.3.A Identify an appropriate confidence interval procedure including the parameter for a population proportion.	3.3.A.1 A confidence interval is an interval estimate for a population parameter. Based on the sample proportion, a confidence interval can be calculated to estimate the value of a single population proportion. The appropriate confidence interval procedure is a one-sample z-interval for a population proportion. 3.3.A.2 The parameter for a confidence interval for a population proportion should reference the proportion, the response variable, and the population in context.
	4.E Justify the use of a chosen statistical inference method by verifying conditions.	3.3.B Justify the appropriateness of constructing a confidence interval for a population proportion by verifying conditions.	3.3.B.1 A one-sample z-interval for a population proportion requires that three conditions be met: 3.3.B.1.i The randomization condition—the data should be collected using a random sample. 3.3.B.1.ii The 10% condition—when sampling without replacement, the population size must be at least 10 times larger than the sample size $(n \le 10\%N)$, where N is the size of the population and n is the sample size.

			3.3.B.1.iii The normality condition—the observed number of successes, $n\hat{p}$, and the observed number of failures, $n(1-\hat{p})$, should be at least 10.	
	3.E Calculate appropriate statistical inference method results.	3.3.C Calculate an appropriate confidence interval for a population proportion.	3.3.C.1 z* denotes a critical value, such that -z* and +z* represent the boundaries enclosing the middle C% of the standard normal distribution, in which C% is an approximate confidence level with which the population proportion is estimated. 3.3.C.2 An interval estimate can be constructed as point estimate (+/- margin of error). For a population proportion, the one-sample z-interval estimate is $\hat{p} \pm z^* \sqrt{\frac{\hat{p}(1-\hat{p})}{n}}$.	
		3.3.D Calculate the standard error and margin of error of a sample statistic for a confidence interval for a population proportion, and estimate a given sample size from the margin of error	3.3.D.1 The standard error (SE) of a statistic is an estimate of the standard deviation of the sampling distribution of the statistic. The standard error of the sample proportion $\hat{p}$ is $SE_{\hat{p}} = \sqrt{\frac{\hat{p}(1-\hat{p})}{n}}$. 3.3.D.2 The standard error quantifies the typical amount that a statistic will vary from the value of the corresponding population parameter. 3.3.D.3 The margin of error of $\hat{p}$ is half the width of the confidence interval and is calculated as the critical value (z*) times the standard error (SE) of $\hat{p}$, which equals $z^* \sqrt{\frac{\hat{p}(1-\hat{p})}{n}}$. 3.3.D.4 The formula for the margin of error (MOE) can be rearranged to solve for n, $n = \frac{(z^*)^2(\hat{p})(1-\hat{p})}{(MOE)^2}$, the minimum sample needed to achieve a given margin of error. For this purpose, if $\hat{p}$ is not defined or unable to be calculated, use $\hat{p}$ = 0.5 in order to find the upper bound for the sample size that will result in a given margin of error.	
Day 4 *3.4* *Justifying a Claim Based on a Confidence Interval for a Population Proportion*	4.F Interpret results of statistical inference methods.	3.4.A Interpret a confidence interval in context for a population proportion.	3.4.A.1 Because the confidence interval for a population proportion is calculated based on a sample from a population, the computed interval may or may not contain the value of the population proportion. 3.4.A.2 The interpretation of the confidence level is that in repeated random sampling with the same sample size, approximately C% of confidence intervals calculated will capture the population proportion, with C representing the numerical value of the confidence level used. 3.4.A.3 When interpreting a C% confidence interval for a population proportion, we say we are C% confident that the interval *(a, b)* contains the true value of the parameter for the population, where a	**The Scribe and the Calculator** Have students work with a partner to construct and interpret a confidence interval for a population proportion. Only one partner is allowed to use the calculator, and only the other partner is allowed to write. When a calculation needs to be made, only the scribe can describe to the calculator operator what buttons to push; when writing needs to be done, only the calculator operator can describe to the scribe what needs to

			represents the lower limit and b represents the upper limit. An interpretation of a confidence interval for a population proportion includes a reference to the parameter with details about the population it represents in the context of the study.	be written. Have students switch roles when constructing and interpreting a confidence interval for the difference of two population proportions.
	4.G Justify a claim based on statistical inference method results.	3.4.B Justify a claim based on a confidence interval for a population proportion.	3.4.B.1 A confidence interval for a population proportion provides a range of plausible values that may serve as convincing evidence to support a particular claim about the population proportion.	
	2.D Identify types of errors and relationships among components in statistical inference methods.	3.4.C Identify the relationships among sample size, confidence interval width, confidence level, and margin of error for a population proportion.	3.4.C.1 For a given sample, increasing the confidence level will result in the following: 3.4.C.1.i The critical value will increase. 3.4.C.1.ii The margin of error will increase. 3.4.C.1.iii The width of the confidence interval will increase. 3.4.C.2 Increasing the sample size decreases the standard error. Thus, when all other things remain the same, the width of the confidence interval for a population proportion tends to decrease as the sample size increases. For a confidence interval for a population proportion with a given confidence level, the width of the interval is approximately proportional to $\frac{1}{\sqrt{n}}$.	
<u>Day 5</u> *3.5* *Setting Up a Test for a Population Proportion*	2.C Identify appropriate statistical inference methods.	3.5.A Identify an appropriate testing method for a population proportion including the parameter for the population proportion.	3.5.A.1 A hypothesis test is a statistical inference procedure that is used to make a decision about the value of a population parameter. The appropriate hypothesis testing procedure is a one-sample z-test for a population proportion. 3.5.A.2 The parameter for a hypothesis test for a population proportion should reference the population parameter, the response variable, and the population in context.	**Error Analysis** Give student pairs a worksheet with 20 sets of hypotheses, each with a common student mistake. Be sure to include hypotheses for a test for a population proportion, a test for the difference between two proportions, a chi-square test for independence, and a chi-square test for homogeneity. Have students circle the incorrect part, write why the circled component is incorrect, and then write the correct hypotheses. Include errors such as using statistics instead of parameters and interchanging the = and > in the two hypotheses.
	2.E Identify the null and alternative hypotheses.	3.5.B Identify the null and alternative hypotheses for a population proportion.	3.5.B.1 In the hypothesis testing procedure, the null hypothesis, H_0, is the statement about a parameter that is assumed to be correct unless there is convincing statistical evidence suggesting otherwise. It is the status quo condition. The alternative hypothesis, H_a, is the claim or belief about a parameter for which evidence is being collected. A researcher's claim or belief about the population parameter is represented by the alternative hypothesis. 3.5.B.2	

			The null hypothesis contains an equality reference (=, ≥, or ≤) . Although the null hypothesis for a one-sided test may include an inequality symbol, in AP Statistics it is tested at the boundary of equality. The alternative hypothesis with < or > is called one-sided, and the alternative hypothesis with ≠ is called two-sided. 3.5.B.3 The null hypothesis for a one-sample z-test for a population proportion is as follows: $H_0: p = p_0$, where p_0 is the null hypothesized value for the population proportion. A one-sided alternative hypothesis for a one-sample z-test for a population proportion is either $H_a: p < p_0$ or $H_a: p > p_0$. A two-sided alternative hypothesis is $H_a: p \neq p_0$.	
	4.E Justify the use of a chosen statistical inference method by verifying conditions	3.5.C Justify the appropriateness of a hypothesis test for a population proportion by verifying conditions.	3.5.C.1 A one-sample z-test for a population proportion requires that three conditions be met: 3.5.C.1.i The randomization condition—the data should be collected using a random sample. 3.5.C.1.ii The 10% condition—when sampling without replacement, the population size must be at least 10 times larger than the sample size $(n \leq 10\%N)$, where N is the size of the population and *n* is the sample size. 3.5.C.1.iii The normality condition—the expected number of successes, np_0, and the expected number of failures, $n(1-p_0)$, should be at least 10.	
<u>Day 6</u> *3.6* *p-Values*	4.F Interpret results of statistical inference methods.	3.6.A Interpret the p-value of a hypothesis test for a population proportion	3.6.A.1 Given the null hypothesis is true, there is a probability distribution of the test statistic called the null distribution. Using the null distribution, the p-value is the probability of obtaining a test statistic as extreme or more extreme (i.e., in the direction of the alternative hypothesis) than the test statistic that is observed given that the null hypothesis is true. That is, when x is the test statistic, the p-value is determined by finding the following: 3.6.A.1.i The probability at or above the observed value of the test statistic $(P(z \geq x))$, if the alternative is > 3.6.A.1.ii The probability at or below the observed value of the test statistic $(P(z \leq x))$, if the alternative is < 3.6.A.1.iii The probability less than or equal to the negative of the absolute value of the test statistic plus the probability greater than or equal to the absolute value of the test statistic,	

			$\left(P\left(z \le -\lvert x\rvert\right)\right)+\left(P\left(z \ge \lvert x\rvert\right)\right)$, if the alternative is ≠ 3.6.A.2 If the distribution of the test statistic has been simulated, the p-value is the proportion of values in the null distribution that are as extreme or more extreme than the observed value of the test statistic. This is as follows: 3.6.A.2.i The proportion at or above the observed value of the test statistic, if the alternative is > 3.6.A.2.ii The proportion at or below the observed value of the test statistic, if the alternative is < 3.6.A.2.iii The proportion less than or equal to the negative of the absolute value of the test statistic plus the proportion greater than or equal to the absolute value of the test statistic, if the alternative is ≠ 3.6.A.3 An interpretation of the p-value of a hypothesis test for a population proportion should include a statement that the p-value is computed by assuming the null hypothesis is true (i.e., by assuming the true population proportion is equal to the particular value stated in the null hypothesis in context). 3.6.A.4 Small p-values indicate that the observed value of the test statistic would be unusual if the null hypothesis were true and therefore provide evidence for the alternative hypothesis. The lower the p-value, the more convincing the statistical evidence for the alternative hypothesis. 3.6.A.5 p-values that are not small indicate that the observed value of the test statistic would not be unusual if the null hypothesis were true and therefore do not provide convincing statistical evidence for the alternative hypothesis, nor do they provide evidence that the null hypothesis is true.	
<u>Day 7</u> *3.7* *Carrying Out a Test for a Population Proportion*	3.E Calculate appropriate statistical inference method results.	3.7.A Calculate an appropriate test statistic and p-value for testing a hypothesis about a population proportion	3.7.A.1 The test statistic for testing a population proportion is $z=\frac{\hat{p}-p_0}{\sqrt{\frac{p_0(1-p_0)}{n}}}$. The z-statistic has a standard normal distribution when the null hypothesis is true. 3.7.A.2 The distribution of the test statistic assuming the null hypothesis is true (null distribution) can be approximated by a probability model (e.g., a theoretical distribution such as the standard normal distribution). 3.7.A.3 The p-value of a one-sample z-test for a population proportion is found from the standard normal distribution using a table or technology.	**Sentence Starters** For a given question, provide students with a set of hypotheses, p-value, significance level, and context. Have them compare the p-value to the significance level to determine whether to reject the null hypothesis. Use a sentence starter with blanks to fill in, and have students write a sentence in context explaining whether they have enough evidence to reject H0 or if they will fail to reject H0. Make sure students avoid the common mistake of implying that evidence supports an accept H0 conclusion or a reject H0 conclusion.
	4.G Justify a claim based on statistical inference method results.	3.7.B Justify a claim about the population based on the results of a hypothesis test for a population proportion.	3.7.B.1 The significance level of a hypothesis test, denoted by α, is the predetermined probability of rejecting the null hypothesis given that it is true. The significance level may be given or determined by the researcher. The relationship between a p-value and the significance level of a hypothesis test	

			determines whether a result is statistically significant. 3.7.B.2 A formal decision in a hypothesis test explicitly compares the p-value to the significance level, α . If the p-value ≤ α , then reject the null hypothesis, $H_0: p = p_0$. If the p-value > α,, then fail to reject the null hypothesis. 3.7.B.3 Rejecting the null hypothesis means there is convincing statistical evidence to support the alternative hypothesis. Failing to reject the null hypothesis means there is not convincing statistical evidence to support the alternative hypothesis. 3.7.B.4 A hypothesis test can lead to rejecting or not rejecting the null hypothesis but can never lead to concluding or proving that the null hypothesis is true. Lack of statistical evidence for the alternative hypothesis is not the same as evidence for the null hypothesis. 3.7.B.5 The results of a hypothesis test for a population proportion can serve as the statistical reasoning to support the answer to an investigative question about the population that was sampled. 3.7.B.6 A conclusion for the hypothesis test for a population proportion is stated in context consistent with, and in terms of, the alternative hypothesis using non-definitive language. The conclusion should contain a reference to the parameter and the population.	
Day 8	**Mid-Unit Assessment**			
Day 9 *3.8 Potential Errors When Performing Tests*	2.D Identify types of errors and relationships among components in statistical inference methods.	3.8.A Identify Type I and Type II errors.	3.8.A.1 A Type I error occurs when there is convincing statistical evidence that the alternative hypothesis is true (due to the small p-value), but it is not. 3.8.A.2 A Type II error occurs when there is not convincing statistical evidence that the alternative hypothesis is true (due to the large p-value), but it is. 3.8.A.3 The power of a hypothesis test is the probability that a hypothesis test will correctly reject the false null hypothesis.	
	3.C Calculate and estimate expected counts, percentages, probabilities, and intervals.	3.8.B Calculate the probability of Type I and Type II errors.	3.8.B.1 The probability of making a Type I error is defined as the significance level, α. For a given study and hypothesis test, the probability of making a Type I error is typically set to a small value (e.g., 0.01, 0.05, 0.10) prior to collecting the data. 3.8.B.2 The probability of making a Type II error is 1 - power.	
	2.D Identify types of errors and relationships among	3.8.C Identify the factors that affect the probability of errors	3.8.C.1 For a given study and hypothesis test, the probability of a Type II error should ideally be small, and thus, the power will be large (e.g., P(Type II error) = 0.20 and power = 0.80). The probability of a Type	

	components in statistical inference methods.	in hypothesis testing.	II error decreases and the power increases when any one of the following occurs, provided the others do not change: 3.8.C.1.i Sample size(s) increases. 3.8.C.1.ii Standard error decreases. 3.8.C.1.iii True parameter value is farther from the null hypothesis. 3.8.C.1.iv Significance level (α) of a test increases.
	4.D Interpret statistical calculations and results to assess meaning or a claim.	3.8.D Interpret Type I and Type II errors.	3.8.D.1 In some studies, making a Type I error may have more serious consequences than making a Type II error. In other studies, making a Type II error may have more serious consequences than making a Type I error. The consequences of each error should be considered prior to conducting the study. 3.8.D.2 Because the significance level, α, is the probability of making a Type I error, the consequences of a Type I error influence decisions about a significance level. 3.8.D.3 Because sample size influences the probability of making a Type II error, the consequences of a Type II error influence decisions about how large the sample size should be.
<u>Day 10</u> *3.9 Sampling Distributions for the Difference Between Sample Proportions*	3.D Calculate means, standard deviations, and parameters for probability distributions.	3.9.A Calculate the mean and standard deviation of the sampling distribution for the difference between two sample proportions.	3.9.A.1 For two independent populations, with population proportions p_1 and p_2, when the sampled values are independent, the sampling distribution for the difference in sample proportions, $\hat{p}_1 - \hat{p}_2$, has a mean, $\mu_{\hat{p}_1-\hat{p}_2} = p_1 - p_2$ and standard deviation, $\sigma_{\hat{p}_1-\hat{p}_2} = \sqrt{\frac{p_1(1-p_1)}{n_1} + \frac{p_2(1-p_2)}{n_2}}$.
	4.E Justify the use of a chosen statistical inference method by verifying conditions.	3.9.B Justify the appropriateness of conditions for the sampling distribution for the difference between two sample proportions.	3.9.B.1 When sampling without replacement, two conditions must be met: 3.9.B.1.i The randomization condition—the data should be collected using two independent random samples. 3.9.B.1.ii The 10% condition—the size of each sample should be less than or equal to 10% of the respective population size: $n_1 \le 10\%N$ and $n_2 \le 10\%N_2$, where N is the size of population 1 and N_2 is the size of population 2. The sample sizes are represented as n_1 and n_2. 3.9.B.2 If the data come from an experiment, the data only need to meet the randomization condition. The treatments must be randomly assigned to the experimental units to meet the randomization condition. 3.9.B.3 The sampling distribution for the difference between sample proportions, $\hat{p}_1 - \hat{p}_2$, will have an approximately normal distribution provided both sample sizes are large enough. To ensure that both samples are large enough, the data must meet the following conditions: $n_1p_1 \ge 10$, $n_1(1-p_1) \ge 10$, $n_2p_2 \ge 10$, and $n_2(1-p_2) \ge 10$ are the expected number of successes and $n_1(1-p_1)$ and $n_2(1-p_2)$ are the expected number of failures.

	4.D Interpret statistical calculations and results to assess meaning or a claim.	3.9.C Interpret the mean, standard deviation, and probabilities for the sampling distribution for the difference between two sample proportions.	3.9.C.1 The mean, standard deviation, and probabilities for the sampling distribution for the difference between two sample proportions should be interpreted within the context of two specific populations.
Day 11-12 *3.10 Constructing a Confidence Interval for the Difference Between Two Population Proportions*	2.C Identify appropriate statistical inference methods.	3.10.A Identify an appropriate confidence interval procedure including the parameters for the difference between two population proportions.	3.10.A.1 Based on the sample data, a confidence interval can be calculated to estimate the difference between two population proportions. The appropriate confidence interval procedure is a two-sample z-interval for a difference between population proportions. 3.10.A.2 The parameters of a confidence interval for the difference between two population proportions should refer to the difference in the proportions, the response variable, and the populations in context.
	4.E Justify the use of a chosen statistical inference method by verifying conditions.	3.10.B Justify the appropriateness of constructing a confidence interval for the difference between two population proportions by verifying conditions.	3.10.B.1 A two-sample z-interval for a difference between two population proportions requires that three conditions be met: 3.10.B.1.i The randomization condition—the data should be collected using two independent random samples or a randomized experiment. 3.10.B.1.ii The 10% condition—when sampling without replacement, the size of each sample should be less than or equal to 10% of the respective population size: $n_1 \le 10\%N_1$ and $n_2 \le 10\%N_2$, where N_1 is the size of population 1 and N_2 is the size of population 2. The sample sizes are represented as n_1 and n_2. (Note: This condition is unnecessary when the data are from a randomized experiment.) 3.10.B.1.iii The normality condition—the number of observed successes, $n_1\hat{p}_1$, and $n_2\hat{p}_2$, and number of observed failures, $n_1(1-\hat{p}_1)$ and $n_2(1-\hat{p}_2)$, for both samples are all at least 10.
	3.E Calculate appropriate statistical inference method results.	3.10.C Calculate an appropriate confidence interval for the difference between two population proportions.	3.10.C.1 The point estimate for the difference between two population proportions is $(\hat{p}_1 - \hat{p}_2)$. 3.10.C.2 For the difference between two population proportions, the interval estimate can be constructed as point estimate +/- (margin of error). The interval estimate for the difference between two population proportions is $(\hat{p}_1 - \hat{p}_2) \pm z^* \sqrt{\frac{\hat{p}_1(1-\hat{p}_1)}{n_1} + \frac{\hat{p}_2(1-\hat{p}_2)}{n_2}}$
		3.10.D Calculate the standard error and margin of error for estimating the difference between two population proportions.	3.10.D.1 The standard error (SE) for the difference between two population proportions is $SE_{\hat{p}_1-\hat{p}_2} = \sqrt{\frac{\hat{p}_1(1-\hat{p}_1)}{n_1} + \frac{\hat{p}_2(1-\hat{p}_2)}{n_2}}$. 3.10.D.2 For the difference between two population proportions, the margin of error is the critical value (z*) times the standard error (SE) of the difference between the two proportions, which equals

			$z^* \sqrt{\frac{\hat{p}_1(1-\hat{p}_1)}{n_1} + \frac{\hat{p}_2(1-\hat{p}_2)}{n_2}}$.	
Day 13 *3.11* *Justifying a Claim Based on a Confidence Interval for the Difference Between Two Population Proportions*	4.F Interpret results of statistical inference methods.	3.11.A Interpret a confidence interval in context for the difference between two population proportions.	3.11.A.1 Because the confidence interval for the difference between two population proportions is calculated based on samples from two populations, the computed interval may or may not contain the value for the difference between those two population proportions. 3.11.A.2 The interpretation of the confidence level is as follows: In repeated random sampling with the same sample sizes from the same populations, approximately C% of confidence intervals created will capture the difference between the two population proportions, where C represents the numerical value of the confidence level used. 3.11.A.3 When interpreting a C% confidence interval for the difference between two population proportions, we say we are C% confident that the interval *(a, b)*, contains the parameter for the difference between the populations, where a represents the lower limit and b represents the upper limit. An interpretation of a confidence interval for the difference between two population proportions includes a reference to the parameter with the details about the populations it represents in the context of the study.	**The Scribe and the Calculator** (see Topic 3.4)
	4.G Justify a claim based on statistical inference method results.	3.11.B Justify a claim based on a confidence interval for the difference between two population proportions.	3.11.B.1 A confidence interval for the difference between two population proportions provides an interval of values that may provide convincing evidence to support a particular claim about the difference between the two population proportions. For example, if the interval contains 0, then there is insufficient evidence to conclude there is a difference between the two population proportions. If the interval does not contain 0, there is sufficient evidence to conclude there is a difference between the two population proportions	
Day 14 *3.12* *Setting Up a Test for the Difference Between Two Population Proportions*	2.C Identify appropriate statistical inference methods.	3.12.A Identify an appropriate testing method for the difference between population proportions including the parameters.	3.12.A.1 The appropriate testing method for the difference between two population proportions is a two-sample z-test for the difference between two population proportions. 3.12.A.2 The parameters for a hypothesis test for the difference between two population	**Error Analysis** (see Topic 3.5)

			proportions should reference the population parameters, the response variables, and the populations in context.	
	2.E Identify the null and alternative hypotheses.	3.12.B Identify the null and alternative hypotheses for the difference between population proportions.	3.12.B.1 For a two-sample z-test for the difference between two population proportions, the null hypothesis indicates no difference. The null hypothesis for the difference between two population proportions can be written as either $H_0: p_1 = p_2$ or $H_0: p_1 - p_2 = 0$. A one-sided alternative hypothesis for the difference between two population proportions can be written as either $H_a: p_1 < p_2$ or equivalently $H_a: p_1 - p_2 < 0$, or $H_a: p_1 > p_2$ or equivalently $H_a: p_1 - p_2 > 0$. A two-sided alternative hypothesis for the difference between two population proportions can be written as either $H_a: p_1 \neq p_2$ or equivalently $H_a: p_1 - p_2 \neq 0$.	
	4.E Justify the use of a chosen statistical inference method by verifying conditions.	3.12.C Justify the appropriateness of a hypothesis test for the difference between two population proportions by verifying conditions.	3.12.C.1 A two-sample z-test for a difference between two population proportions requires that three conditions be met: 3.12.C.1.i The randomization condition—the data should be collected using two independent random samples or a randomized experiment. 3.12.C.1.ii The 10% condition—when sampling without replacement, the size of each sample should be less than or equal to 10% of the respective population size: $n_1 \leq 10\% N_1$ and $n_2 \leq 10\% N_2$, where N_1 is the size of population 1 and N_2 is the size of population 2. The sample sizes are represented as n_1 and n_2. (Note: This condition is unnecessary when the data are from a randomized experiment.) 3.12.C.1.iii The normality condition— $n_1\hat{p}_c, n_1\left(1-\hat{p}_c\right)$, $n_2\hat{p}_c$, and $n_2\left(1-\hat{p}_c\right)$, must all be at least 10, with $\hat{p}_c = \frac{n_1\hat{p}_1 + n_2\hat{p}_2}{n_1 + n_2}$ being the combined (or pooled) proportion	

			assuming that H_0 is true $(H_0: p_1 = p_2 \text{ or } H_0: p_1 - p_2 = 0)$.	
Day 15 *3.13* *Carrying Out a Test for the Difference Between Two Population Pro≤portions*	3.E Calculate appropriate statistical inference method results.	3.13.A Calculate an appropriate test statistic and p-value for testing a hypothesis for the difference between two population proportions.	3.13.A.1 The test statistic for the difference between two population proportions is $z = \frac{\left(\hat{p}_1 - \hat{p}_2\right) - 0}{\sqrt{\hat{p}_c\left(1-\hat{p}_c\right)}\sqrt{\frac{1}{n_1}+\frac{1}{n_2}}}$, where $\hat{p}_c = \frac{n_1\hat{p}_1 + n_2\hat{p}_2}{n_1 + n_2}$ is the proportion of successes for the two groups combined. The z-statistic has a standard normal distribution when the null hypothesis is true. 3.13.A.2 The p-value for a two-sample z-test for the difference between two population proportions can be found from the standard normal distribution using a table or technology.	**Sentence Starters** (see Topic 3.7)
	4.F Interpret results of statistical inference methods.	3.13.B Interpret the p-value of a hypothesis test for the difference between two population proportions.	3.13.B.1 The p-value is the probability of obtaining a test statistic as extreme or more extreme than the test statistic that was observed (i.e., in the direction of the alternative hypothesis) given that the null hypothesis is true. An interpretation of the p-value of a hypothesis test for a difference between two population proportions should include a statement that the p-value is computed assuming the null hypothesis is true (i.e., by assuming that the true population proportions are equal to each other in context).	
	4.G Justify a claim based on statistical inference method results.	3.13.C Justify a claim about the populations based on the results of a hypothesis test for the difference between two population proportions.	3.13.C.1 A formal decision in a hypothesis test for the difference between two population proportions explicitly compares the p-value to the significance level, α. If the p-value ≤ α then reject the null hypothesis, $H_0: p_1 = p_2$ or $H_0: p_1 - p_2 = 0$. If the p-value > α, then fail to reject the null hypothesis. 3.13.C.2 The results of a hypothesis test for the difference between two population proportions can serve as the statistical reasoning to support the answer to an investigative question about the two populations that were sampled. 3.13.C.3 A conclusion for the hypothesis test for the difference between two population	

			proportions is stated in context consistent with, and in terms of, the alternative hypothesis using nondefinitive language. The conclusion should contain a reference to the parameters and the populations.	
<u>Day 16</u> *3.14* *Setting Up a Chi-Square Test for Homogeneity or Independence*	4.C Describe distributions and compare relative positions of points within a distribution.	3.14.A Describe chi-square distributions.	3.14.A.1 The chi-square statistic measures the distance between observed and expected counts relative to expected counts. 3.14.A.2 Chi-square distributions have positive values and are skewed right. Within this family of density curves, the skew becomes less pronounced with increasing degrees of freedom.	**Error Analysis** (see Topic 3.5)
	2.C Identify appropriate statistical inference methods.	3.14.B Identify an appropriate testing method for comparing distributions in two-way tables of categorical data including the populations and variables	3.14.B.1 To determine whether the distributions of a categorical variable for two or more populations are different, the appropriate test is the chi-square test for homogeneity. 3.14.B.2 A chi-square test for homogeneity should reference the categorical variable and the populations in context. 3.14.B.3 To determine whether row and column variables in a two-way table of categorical data might be associated in the single population from which the data were sampled, the appropriate test is the chi-square test for independence. 3.14.B.4 A chi-square test for independence should reference the categorical variables and the population in context.	
	2.E Identify the null and alternative hypotheses.	3.14.C Identify the null and alternative hypotheses for a chi-square test for homogeneity or independence.	3.14.C.1 The appropriate null hypothesis for a chi-square test for homogeneity is H_0: there is no difference in the distributions of the categorical variable across populations or treatments. The appropriate alternative hypothesis for a chi-square test for homogeneity is H_a: there is a difference in the distributions of the categorical variable across populations or treatments. 3.14.C.2 The appropriate null hypothesis for a chi-square test for independence is H_0: there is no association between two categorical variables in a given population or the two categorical variables in a given population are independent of each other. The appropriate alternative hypothesis for a chi-square test for independence is H_a: there is an association between two categorical variables in a given population or the two categorical	

			variables in a given population are not independent of each other.	
	4.E Justify the use of a chosen statistical inference method by verifying conditions.	3.14.D Justify the appropriateness of a chi-square test for independence or homogeneity by verifying conditions.	3.14.D.1 A chi-square test for homogeneity or independence requires that three conditions must be met: 3.14.D.1.i The randomization condition—the test of independence states that the data should be collected using a random sample. The test for homogeneity states that the data should be collected using independent random samples or a randomized experiment. 3.14.D.1.ii The 10% condition—when sampling without replacement, check that $n \leq 10\%N$, where N is the size of the population and n is the sample size. (Note: This condition is unnecessary when the data are from a randomized experiment.) 3.14.D.1.iii The expected counts condition—all expected counts should be greater than 5.	
<u>Day 17</u> *3.15* *Carrying Out a Chi-Square Test for Homogeneity or Independence*	3.C Calculate and estimate expected counts, percentages, probabilities, and intervals.	3.15.A Calculate expected counts for two-way tables of categorical data	3.15.A.1 The expected counts (under the null hypothesis) in a particular cell of a two-way table of categorical data can be calculated using the formula $\text{expected count} = \frac{(\text{row total})(\text{column total})}{\text{total table}}$	**Sentence Starters** (see Topic 3.7)
	3.E Calculate appropriate statistical inference method results.	3.15.B Calculate the appropriate test statistic and p-value for a chisquare test for homogeneity or independence.	3.15.B.1 The appropriate test statistic for a chi-square test for homogeneity or independence is the chi-square statistic $\chi^2 = \sum \frac{(\text{Observed Count} - \text{Expected Count})^2}{\text{Expected Count}}$ where the sum is taken over all cells of the two-way table. The chi-square statistics have a chi-square distribution with degrees of freedom equal to (number of rows − 1)(number of columns −1) when the null hypothesis is true. 3.15.B.2 The p-value for a chi-square test for independence or homogeneity is found from a chi-square distribution using a table or technology.	
	4.F Interpret results of statistical inference methods.	3.15.C Interpret the p-value for the chi-square test for homogeneity or independence.	3.15.C.1 The p-value is the probability of obtaining a test statistic as extreme or more extreme than the test statistic that was observed (i.e., in the direction of the alternative hypothesis) given that the null hypothesis is true. An interpretation of the p-value for the chi-square test for homogeneity or independence should include a statement that the p-value is computed by assuming the null hypothesis is true in context.	

	4.G Justify a claim based on statistical inference method results.	3.15.D Justify a claim about the population(s) based on the results of a chi-square test for homogeneity or independence.	3.15.D.1 A formal decision in a hypothesis test explicitly compares the p-value to the significance level, α. If the p-value $\leq \alpha$, then reject the null hypothesis for the appropriate chi-square test. If the p-value $> \alpha$, then fail to reject the null hypothesis. 3.15.D.2 The results of a chi-square test for homogeneity or independence can serve as the statistical reasoning to support the answer to an investigative question about the population that was sampled (independence) or the populations that were sampled (homogeneity). 3.15.D.3 A conclusion for a chi-square test for homogeneity or independence is stated in context consistent with, and in terms of, the alternative hypothesis using non-definitive language. The conclusion should contain a reference to the population(s).	
Day 18	**Unit Test: AP Progress Check 3**			

Unit Title	
Unit 4: Inference for Quantitative: Means	
Relevant Standards: Bold indicates priority	
2.C, 2.D, 2.E, 3.D, 3.E, 4.C, 4.D, 4.E, 4.F, 4.G	
Essential Question(s)	**Enduring Understanding(s)**
• How can we compare the average salaries of different professions across different regions of a country? • How can we evaluate the effectiveness of a new medicine in lowering cholesterol for older adults? • How can a pre-test and a post-test be used to evaluate student learning?	• Sampling distributions provide the foundation for making inferences about population means. • Confidence intervals estimate population means while quantifying uncertainty. • Hypothesis tests provide evidence for evaluating claims about population means. • The validity of statistical conclusions depends on appropriate assumptions, conditions, and context.
Demonstration of Learning	**Pacing for Unit**

Progress Check 4
• Multiple-choice: ~49 questions
• Free-response: 3 questions
  ○ Question 1: Inference
  ○ Question 2: Inference
  ○ Question 3: Inference
 	
The additional online question bank will be used to create a mid-unit quiz and other checks for understanding throughout the unit.
 	
College Board AP Exam
Section I MCQ Weighting: 10–20%
• t-Procedures for Population Means: Performing 1-sample t-intervals/tests, matched-pairs t-procedures, and 2-sample t-intervals/tests.
• Condition Verification: Checking independence and the Normal/Large Sample condition (n≤30 or checking sample plots for severe skewness/outliers) when population standard deviation is unknown.
• Interpretation: Interpreting confidence levels, confidence intervals, p-values, and Type I / Type II errors in context
 	
See AP Exam Overview for more information
	12 Block Periods
	
	NOTE:
	Midterm & AP Exam Review / Mock Exams - 11 Blocks
	Flexibility/Buffer/Post-AP Exam Project - 6 Blocks

Family Overview (link below)	**Integration of Technology:**
AP Statistics FAMILY MATERIALS	• Construct t-intervals and t-tests using calculators and statistical software. • Interpret technology-generated output. • Explore sampling distributions through simulation. • Analyze real-world quantitative datasets using technology.
Unit-specific Vocabulary	**Aligned Unit Materials, Resources, and Technology (beyond core resources)**
Mean Population mean Sample mean Sampling distribution Standard error Degrees of freedom t-distribution One-sample t-interval Two-sample t-interval Two-sample t-test Confidence interval Hypothesis test P-value Type I error Type II error Power	www.mathmedic.com www.desmos.com www.stapplet.com https://skewthescript.org/

One-sample t-test Matched-pairs t-test	Assumptions Conditions

Opportunities for Interdisciplinary Connections:	Anticipated misconceptions
• Biology: treatment and control group comparisons. • Medicine: clinical trial outcomes. • Environmental Science: comparing environmental measurements. • Economics: income and spending analyses. • Physical Education and Sports Science: performance comparisons.	1. Analyzing paired data with a two-sample independent t-procedure instead of a matched-pairs t-procedure. 2. Believing t-procedures require raw sample data to be strictly Normally distributed regardless of sample size. 3. Confusing sample standard deviation (s) with standard error (SE). 4. Using z-critical values instead of t-critical values when analyzing sample means with an unknown population standard deviation. 5. Equating statistical significance (low p-value) with real-world practical significance.
Connections to Prior Units	**Connections to Future Units**
• Extends inference concepts developed in Unit 3. • Relies on probability and sampling distributions from Unit 2. • Uses study-design principles introduced in Unit 1.	• Prepares students for regression-based inference. • Reinforces interpretation of confidence intervals, hypothesis tests, and statistical conclusions.

Differentiation through *Universal Design for Learning*

	Engagement	Representation	Action & Expression
2.C	"Casino & Game Show Audit" evaluating game rules to decide whether outcomes are governed by Discrete, Binomial B(n,p), Geometric G(p), or Continuous Normal probability decision models.	Flowchart decision tree mapping random variable features (fixed trial count n vs. count until 1st success, discrete counts vs. continuous measurements) to the appropriate probability model.	Build an interactive digital model selector or record an audio walkthrough classifying three complex random variable scenarios.
2.D	"Quality Control Inspection Lab" setting decision boundaries for product testing and calculating the probability of false alarms (Type I error, \alpha) versus missing a defect (Type II error, \beta).	Dual Normal/Binomial distribution curves illustrating overlapping null and alternative distributions, visually shading \alpha (Type I area) and \beta (Type II area).	Construct a visual error probability slide deck or create an interactive spreadsheet calculating how shifting the decision cutoff changes α or β
2.E	"Is the Game Rigged?" challenge translating probability claims (e.g., "This spinner lands on win 50% of the time") into baseline parameter hypotheses (H0: p = 0.50 vs. Ha: p > 0.50).	Side-by-side reference chart translating verbal claims ("unfair advantage," "yields higher average payout") into symbolic parameters (p, \mu) and H_0/H_a statements.	Write symbolic hypotheses for four probability distribution prompts and record a video explaining how parameter assumptions define H0.
3.E	"Probability Escape Room" computing exact tail probabilities and cumulative probabilities under specified probability models to unlock progressive stages.	Step-by-step formula execution guides pairing exact Binomial/Normal formulas with TI-84/calculator syntax (binomcdf, normalcdf) side-by-side.	Submit a probability calculation portfolio featuring both handwritten formula work and calculator or computational script outputs.
4.E	"BINS Inspector" auditing probability scenarios to spot violated conditions (e.g., checking Binary outcomes, Independence, Fixed n, Constant p, 10% condition, or $np \geq 10$, $n(1-p) \geq 10$.	Visual checklist for **BINS** (Binomial settings) and Normal approximation criteria with visual status indicators (satisfied vs. violated).	Produce a "Model Verification Report" evaluating whether a real-world scenario satisfies Binomial or Normal distribution conditions.
4.F	"Probability Translator" converting raw cumulative probability outputs into consumer-facing explanations regarding luck versus evidence of model bias.	Sentence-template bank providing standardized AP phrasing: *"Assuming [baseline model parameter], the probability of observing [result] or more extreme by chance is [probability]."*	Record a video or podcast segment explaining what a calculated probability result implies about a casino game or manufacturing standard.
4.G	"Fair Game Courtroom" using probability calculations as evidence to deliver a binding	Decision tree graphic linking probability thresholds (P(X) < \alpha) to final conclusions	Write a complete CER justification essay or deliver a closing argument video evaluating a baseline probability

	decision on whether a process or game deviates from its claimed parameter.	regarding the validity of a baseline probability claim.	claim based on calculated tail probabilities.

Supporting Multilingual/English Learners (*CELP standards*)

	Emerging	Expanding	Bridging
2.C	Match quantitative inference cards to visual study descriptions.	Select the appropriate t-inference procedure (distinguishing 2-sample independent vs. paired t-tests) using a graphic organizer.	Differentiate between independent 2-sample t-procedures and paired t-procedures based on subtle experimental/sampling design descriptions.
2.D	Match Type I / Type II error definitions to t-test scenario diagrams with picture cues.	Describe consequences of Type I and Type II errors in a quantitative study using structured cause-and-effect templates.	Evaluate how changing sample size n or population standard deviation \sigma impacts t-distribution shape, degrees of freedom, and test power.
2.E	Select H0 and Ha statements using mean parameter symbols from visual choice cards.	Write H0 and Ha hypotheses for means in symbols and defined words using structured sentence frames..	Formulate hypotheses for 1-sample, paired, and 2-sample t-tests, precisely defining population means and mean differences in context.
3.E	Locate degrees of freedom, t-statistic, and p-value on a computer output screenshot using a visual key.	Calculate t-statistics, degrees of freedom, and confidence intervals for means using annotated formula guides and t-tables.	Compute 1-sample, 2-sample, and paired t-test statistics, p-values, and confidence intervals using technology and mathematical formulas.
4.E	Check off conditions (*Random, 10% condition, Normal/Large Sample or no strong skew/outliers*) on a visual checklist.	Check and describe t-inference conditions, sketching sample graphs to verify the Normal/Large Sample condition using guided templates.	Evaluate t-procedure conditions, assessing sample plot skewness/outliers when n < 30, and justify whether inference remains robust.
4.F	Complete a standard confidence interval interpretation frame for means: "*We are 95% confident that the true mean [context] is...*"	Interpret t-test p-values and confidence intervals for means in context using structured sentence frames.	Interpret confidence intervals for mean differences and p-values, highlighting practical vs. statistical significance.
4.G	Circle "Reject H0" or "Fail to Reject H0" based on p-value vs. $\alpha = 0.05$ comparison cards.	Draft formal t-test conclusions linked to claims using structured decision templates ("*There is [sufficient / insufficient] evidence...*").	Synthesize test results and confidence intervals to evaluate real-world claims about population means, addressing directional vs. non-directional claims.

Unit Outline

Lesson Sequence	Skills	Learning Objective	Essential Knowledge	AP Activities *(if available)*
<u>Day 1</u> *4.1 Sampling Distributions for Sample Means*	3.D Calculate means, standard deviations, and parameters for probability distributions.	4.1.A Calculate the mean and standard deviation of a sampling distribution of a sample mean.	4.1.A.1 For a population with population mean μ and population standard deviation σ , when the sampled values are independent, the sampling distribution of the sample mean has mean $\mu_{\bar{x}} = \mu$ and standard deviation $\sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}}$	**Quick Write** Provide students with a prompt such as "Describe how to construct a sampling distribution." Then allow 1 or 2 minutes for them to write a response (e.g., "obtain sample, collect responses, calculate statistic, plot statistic, repeat"). Allow more writing time for more difficult prompts.
	4.E Justify the use of a chosen statistical inference method by verifying conditions.	4.1.B Justify the appropriateness of conditions for the sampling distribution of a sample mean.	4.1.B.1 Sampling without replacement requires that two conditions must be met: 4.1.B.1.i The randomization condition—the data should be collected using a random sample. 4.1.B.1.ii	

			The 10% condition—the population size must be at least 10 times larger than the sample size ($n \leq 10\%N$), where N is the size of the population and n is the sample size. 4.1.B.2 For a quantitative variable, if the population distribution can be modeled by a normal distribution, the sampling distribution of the sample mean, $\bar{x}$, can be modeled with a normal distribution regardless of the sample size. 4.1.B.3 For a quantitative variable, if the population distribution cannot be modeled by a normal distribution, the sampling distribution of the sample mean, $\bar{x}$, can be modeled approximately by a normal distribution, provided $n \geq 30$. If the population distribution is extremely skewed, a sample size much larger than 30 may be needed to ensure the sampling distribution is approximately normal.	
	4.D Interpret statistical calculations and results to assess meaning or a claim.	4.1.C Interpret the mean, standard deviation, and probabilities for the sampling distribution of a sample mean.	4.1.C.1 The mean, standard deviation, and probabilities for a sampling distribution of a sample mean should be interpreted within the context of a specific population.	
<u>Day 2</u> *4.2 Constructing a Confidence Interval for a Population Mean or Population Mean Difference*	4.C Describe distributions and compare relative positions of points within a distribution.	4.2.A Describe t-distributions.	4.2.A.1 t-distributions, also called Student's t-distributions, form a family of symmetric, bell-shaped, standardized distributions with wider tails than that of the standard normal distribution. Specific t-distributions are identified using a parameter known as the number of degrees of freedom (df), which is based on the sample size(s). When the degrees of freedom are small, the t-distribution has a much narrower peak and fatter tails than a normal distribution. As the degrees of freedom increase, the t-distribution more closely resembles the standard normal distribution (mean $\mu = 0$ and standard deviation $\sigma = 1$). 4.2.A.2 t-distributions are used for finding critical values and test statistics for inferences about a population mean, μ, when the population standard deviation, σ , is unknown and the sample standard deviation, s, must be used instead.	**Discussion Groups** Place students in groups of three or four and ask each group to identify the conditions for performing a test about a population mean. For each condition, have them explain why the condition is required and what would go wrong with the test if the condition were violated. Have groups pair up and compare answers. **Round Table** (see Topic 4.3) **Team Challenge: Marking the Text** (see Topic 4.4) **Graphic Organizer** (see Topic 4.7)
	2.C Identify appropriate statistical inference methods.	4.2.B Identify an appropriate confidence interval procedure including the parameter for a	4.2.B.1 The appropriate confidence interval procedure for estimating the population mean of a quantitative variable for one sample is a one-sample t-interval for a population mean. (The	

		population mean or population mean difference.	population standard deviation, σ , is not typically known for distributions for quantitative variables.) 4.2.B.2 For a matched pairs design with two dependent samples, the appropriate analysis calculates differences between pairs of values to produce one sample of differences. The confidence interval procedure for the matched pairs design is a one-sample t-interval for a population mean difference. 4.2.B.3 The parameter for a confidence interval for a population mean or population mean difference should reference the population mean or population mean difference and the response variable, in context. For the population mean difference, it is important to state the order of subtraction for the difference	
	4.E Justify the use of a chosen statistical inference method by verifying conditions.	4.2.C Justify the appropriateness of constructing a confidence interval for a population mean or population mean difference by verifying conditions.	4.2.C.1 A one-sample t-interval for a population mean or population mean difference requires that three conditions be met: 4.2.C.1.i The randomization condition—the data should be collected using a random sample or a randomized experiment. 4.2.C.1.ii The 10% condition—when sampling without replacement, the population size must be at least 10 times larger than the sample size ($n \leq 10\%N$), where N is the size of the population and n is the sample size. 4.2.C.1.iii The sample data condition—it is indicated the population distribution is approximately normal, or $n \geq 30$, or if $n < 30$, the sample data distribution should be free from strong skewness and outliers. For matched pairs, the number of differences should be greater than or equal to 30. If the number of differences is less than 30, the sample of differences should be free from strong skewness and outliers.	
	3.E Calculate appropriate statistical inference method results.	4.2.D Calculate an appropriate confidence interval for a population mean or population mean difference.	4.2.D.1 A point estimate for a population mean is the sample mean, $\bar{x}$, or $\bar{x}_d$ for the sample mean difference. 4.2.D.2 To estimate the population mean for one sample or the population mean difference between values in matched pairs, when the population standard deviation is unknown, the confidence interval is $\bar{x} \pm t^* \frac{s}{\sqrt{n}}$, where t* is the	

			critical value for the central C% of a t-distribution with degrees of freedom n −1.	
		4.2.E Calculate the standard error and margin of error for a sample size for a one-sample t-interval.	4.2.E.1 The standard error (SE) for a sample mean is given by $SE_{\bar{x}} = \frac{s}{\sqrt{n}}$. 4.2.E.2 For a one-sample t-interval for a population mean, the margin of error is the critical value (t*) times the standard error (SE), which equals $\left(t^*\right)\left(\frac{s}{\sqrt{n}}\right)$.	
<u>Day 3</u> *4.3 Justifying a Claim Based on a Confidence Interval for a Population Mean or Population Mean Difference*	4.F Interpret results of statistical inference methods.	4.3.A Interpret a confidence interval in context for a population mean or population mean difference.	4.3.A.1 Because the confidence interval for a population mean or population mean difference is calculated based on a sample from a population, the computed interval may or may not contain the value of the population mean or population mean difference. 4.3.A.2 The interpretation of the confidence level is as follows: In repeated random sampling with the same sample size from the same population, approximately C% of confidence intervals created will capture the population mean or population mean difference, where C represents the numerical value of the confidence level used. 4.3.A.3 When interpreting a C% confidence interval for a population mean or population mean difference, we say we are C% confident the interval *(a, b)* contains the value of the population mean or population mean difference, where a represents the lower limit and b represents the upper limit. An interpretation of a confidence interval for a population mean or population mean difference includes a reference to the parameter.	**Round Table** Arrange students in groups of four and give each student an identical paper containing four different inference procedure problems from Unit 4. Have students complete the first one on their paper and then pass the paper clockwise to another member in their group. That student checks the first problem and then completes the second problem on the paper. Have students rotate again, continuing the process until each student has their original paper back.
	4.G Justify a claim based on statistical inference method results.	4.3.B Justify a claim based on a confidence interval for a population mean or population mean difference.	4.3.B.1 A confidence interval for a population mean or population mean difference provides an interval of values that may serve as convincing evidence to support a particular claim about the population mean or population mean difference.	
	2.D Identify types of errors and relationships among components in statistical inference methods.	4.3.C Identify the relationships among sample size, confidence interval width, confidence level, and margin of error for a	4.3.C.1 For a given sample, increasing the confidence level will result in the following: 4.3.C.1.i The critical value will increase. 4.3.C.1.ii The margin of error will increase.	

		population mean or population mean difference.	4.3.C.1.iii The width of the confidence interval will increase. 4.3.C.2 Increasing the sample size decreases the standard error. Thus, when all other things remain the same, the width of a confidence interval for a population mean or population mean difference tends to decrease as the sample size increases. For a confidence interval for a population mean or population mean difference with a given confidence level, the width of the interval is approximately proportional to $\frac{1}{\sqrt{n}}$.	
<u>Day 4</u> *4.4* *Setting Up a Test for a Population Mean or Population Mean Difference*	2.C Identify appropriate statistical inference methods.	4.4. A Identify an appropriate testing method and parameter for a population mean or population mean difference with unknown σ .	4.4.A.1 The appropriate test for a population mean with unknown population standard deviation σ is a one-sample t-test for a population mean. 4.4.A.2 For a matched pairs design with two dependent samples, the appropriate analysis calculates differences between pairs of values to produce one sample of differences. The hypothesis testing procedure for the matched pairs design is a one-sample t-test for the population mean difference. 4.4.A.3 The parameter for a hypothesis test for a population mean and population mean difference should reference the population parameter, the response variable, and the population in context.	**Team Challenge: Marking the Text** Give students examples of statistical situations. Have them highlight or underline the key phrases to help them determine which statistical test to use for each situation. For example, does it require a significance test or a confidence interval? Does it involve means or proportions? Is there only one variable, or are there two or more variables? **Round Table** (see Topic 4.3) **Graphic Organizer** (see Topic 4.7)
	2.E Identify the null and alternative hypotheses.	4.4.B Identify the null and alternative hypotheses for a population mean or population mean difference with unknown σ.	4.4.B.1 The null hypothesis for a one-sample t-test for a population mean is $H_0: \mu = \mu_0$, in which μ_0 is the null hypothesized value for the population mean. A one-sided alternative hypothesis for a one-sample t-test for a population mean is either $H_a: \mu < \mu_0$ or $H_a: \mu > \mu_0$. A two-sided alternative hypothesis is $H_a: \mu \neq \mu_0$. 4.4.B.2 The null hypothesis for a population mean difference is $H_0: \mu_d = 0$. A one-sided alternative hypothesis for a population mean difference is either $H_a: \mu_d < 0$ or $H_a: \mu_d > 0$. A two-sided alternative hypothesis is $H_a: \mu_d \neq 0$.	
	4.E Justify the use of a chosen statistical inference method by	4.4.C Justify the appropriateness of a	4.4.C.1 A one-sample t-test for a population mean or a population mean difference	

	verifying conditions.	hypothesis test for a population mean or population mean difference by verifying conditions.	requires that three conditions be met: 4.4.C.1.i The randomization condition—the data should be collected using a random sample or a randomized experiment. 4.4.C.1.ii The 10% condition—when sampling without replacement, the population size must be at least 10 times larger than the sample size ($n \leq 10\%N$), where N is the size of the population and n is the sample size. 4.4.C.1.iii The sample data condition—it is indicated the population distribution is approximately normal, or $n \geq 30$, or if $n < 30$, the sample data distribution should be free from strong skewness and outliers. For matched pairs, the number of differences should be greater than or equal to 30. If the number of differences is less than 30, the sample of differences should be free from strong skewness and outliers.	
<u>Day 5</u> *4.5* *Carrying Out a Test for a Population Mean or Population Mean Difference*	3.E Calculate appropriate statistical inference method results.	4.5. A Calculate an appropriate test statistic and p-value for testing a hypothesis about a population mean or population mean difference	4.5.A.1 The test statistic for a one-sample t-test for a population mean or population mean difference is $t = \frac{\bar{x} - \mu_0}{\frac{s}{\sqrt{n}}}$, where t has degrees of freedom n −1. The t-statistic has a t-distribution with degrees of freedom n −1 when the null hypothesis is true. 4.5.A.2 The p-value for a one-sample t-test for a population mean or population mean difference is found using the appropriate t-distribution table or technology.	**Round Table** (see Topic 4.3)
	4.F Interpret results of statistical inference methods.	4.5.B Interpret the p-value of a hypothesis test for a population mean or population mean difference.	4.5.B.1 The p-value is the probability of obtaining a test statistic as extreme or more extreme than the test statistic that was observed (i.e., in the direction of the alternative hypothesis) given that the null hypothesis is true. An interpretation of the p-value of a hypothesis test for a population mean or population mean difference should include a statement that the p-value is computed by assuming that the null hypothesis is true (i.e., by assuming that the population mean is equal to the particular value stated in the null hypothesis in context).	
	4.G Justify a claim based on statistical inference method results.	4.5.C Justify a claim about the population based on the results of a hypothesis test for a population mean or population	4.5.C.1 A formal decision explicitly compares the p-value to the significance level, α. If the p-value $\leq \alpha$, then reject the null hypothesis, $H_0: \mu = \mu_0$. If the	

		mean difference	p-value > α, then fail to reject the null hypothesis. 4.5.C.2 The results of a hypothesis test for a population mean or population mean difference can serve as the statistical reasoning to support the answer to an investigative question about the population that was sampled. 4.5.C.3 A conclusion for the hypothesis test for a population mean or population mean difference is stated in context consistent with, and in terms of, the alternative hypothesis using nondefinitive language. The conclusion should contain a reference to the parameter and the population.	
Day 6 *4.6 Sampling Distributions for the Difference Between Two Sample Means*	3.D Calculate means, standard deviations, and parameters for probability distributions.	4.6.A Calculate the mean and standard deviation of a sampling distribution for the difference between two sample means.	4.6.A.1 For two independent populations with population means μ_1 and μ_2 and population standard deviations σ_1 and σ_2, when the sampled values are independent, the sampling distribution of the difference in sample means $\bar{x}_1 - \bar{x}_2$ has a mean $\mu_{(\bar{x}_1-\bar{x}_2)} = \mu_1 - \mu_2$ and standard deviation $\sigma_{(\bar{x}_1-\bar{x}_2)} = \sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}$.	
	4.E Justify the use of a chosen statistical inference method by verifying conditions.	4.6.B Justify the appropriateness of conditions for the sampling distribution of the difference between two sample means.	4.6.B.1 Sampling without replacement requires that two conditions must be met: 4.6.B.1.i The randomization condition—the data should be collected using two independent random samples. 4.6.B.1.ii The 10% condition—the size of each sample should be less than or equal to 10% of the respective population size: $n_1 \leq 10\%N_1$ and $n_2 \leq 10\%N_2$, where N_1 is the size of population 1 and N_2 is the size of population 2. The sample sizes are represented as n_1 and n_2. 4.6.B.2 If the data come from an experiment, the data only need to meet the randomization condition. The treatments must be randomly assigned to experimental units to meet the randomization condition. 4.6.B.3 The sampling distribution for the difference between sample means, $\bar{x}_1 - \bar{x}_2$, can be modeled with a normal distribution if the two population distributions can each be modeled by a normal distribution. 4.6.B.4 The sampling distribution for the difference between sample means, $\bar{x}_1 - \bar{x}_2$, can be modeled approximately by a normal distribution if the two population distributions cannot be modeled by a normal distribution but $n_1 \geq 30$ and $n_2 \geq 30$.	
	4.D Interpret statistical calculations and results to assess meaning or a claim.	4.6.C Interpret the mean, standard deviation, and probabilities for a sampling	4.6.C.1 The mean, standard deviation, and probabilities for a sampling distribution for the difference between sample means should be interpreted within the context of specific populations.	

		distribution for the difference between sample means.		
<u>Day 7</u> *4.7 Constructing a Confidence Interval for the Difference Between Two Population Means*	2.C Identify appropriate statistical inference methods.	4.7.A Identify an appropriate confidence interval procedure including the parameter for the difference between two population means.	4.7.A.1 Based on the sample data, a confidence interval can be calculated to estimate the difference between two population means. The appropriate confidence interval procedure for two independent samples is a twosample t-interval for the difference between population means. 4.7.A.2 The parameter for a confidence interval for a two-sample t-interval for the difference between population means should reference the difference in the means, the response variable, and the populations in context.	**Graphic Organizer** Have students work in teams of two or three to develop a flowchart for determining which inference procedure from Units 3 and 4 to use in a given setting. **Team Challenge** (See Topic 4.4) **Round Table** (see Topic 4.3)
	4.E Justify the use of a chosen statistical inference method by verifying conditions.	4.7.B Justify the appropriateness of constructing a confidence interval for the difference between two population means by verifying conditions.	4.7.B.1 A two-sample t-interval for a difference between population means requires that three conditions be met: 4.7.B.1.i The randomization condition—the data should be collected using two independent random samples or a randomized experiment. 4.7.B.1.ii The 10% condition—when sampling without replacement, the size of each sample should be less than or equal to 10% of the respective population size: $n_1 \leq 10\% N_1$ and $n_2 \leq 10\% N_2$, where N_1 is the size of population 1 and N_2 is the size of population 2. The sample sizes are represented as n_1 and n_2. (Note: This condition is unnecessary when the data are from a randomized experiment). 4.7.B.1.iii The sample data condition—both samples should have a sample size greater than or equal to 30 or it is indicated that both population distributions are approximately normal. If either sample size is less than 30, both sample data distributions should be free from strong skewness and outliers.	
	3.E Calculate appropriate statistical inference method results.	4.7.C Calculate an appropriate confidence interval for the difference between two population means.	4.7.C.1 A point estimate for the difference between two population means is the difference in sample means, $\bar{x}_1 - \bar{x}_2$. 4.7.C.2 For the difference between population means when the population standard deviations are unknown, the confidence interval can be constructed as point estimate ±(margin of error). The confidence interval for the difference between population means	

			$(\bar{x}_1 - \bar{x}_2) \pm t^* \sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}$, is , where t* are the critical values for the central C% of a t-distribution with appropriate degrees of freedom that can be found using technology. The degrees of freedom fall between $n_1 + n_2 - 2$ and the smaller of $n_1 - 1$ and $n_2 - 1$.	
		4.7.D Calculate the standard error and margin of error for estimating the difference between two population means.	4.7.D.1 The standard error for the difference between two sample means is $SE_{\bar{x}_1 - \bar{x}_2} = \sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}$, where s_1 and s_2 are the sample standard deviations. 4.7.D.2 For the difference between two sample means, the margin of error is the critical value (t*) times the standard error (SE) of the difference of two sample means, which equals $t^* \sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}$.	
Day 8	**Mid-Unit Assessment**			
Day 9 *4.8 Justifying a Claim Based on a Confidence Interval for the Difference Between Two Population Means*	4.F Interpret results of statistical inference methods.	4.8.A Interpret a confidence interval in context for the difference between two population means	4.8.A.1 Because the confidence interval for the difference between two population means is calculated based on samples from two populations, the computed interval may or may not contain the value for the difference between the two population means. 4.8.A.2 The interpretation of the confidence level is as follows: In repeated random sampling with the same sample size from the same populations, approximately C% of confidence intervals created will capture the difference between the two population means, where C represents the numerical value of the confidence level used. 4.8.A.3 When interpreting a C% confidence interval for the difference between two population means, we say we are C% confident that the interval *(a, b)* contains the value of the difference in the population means, where a represents the lower limit and b represents the upper limit. An interpretation of a confidence interval for the difference between two population means includes a reference to the difference in the population	**Team Challenge** (See Topic 4.4) **Round Table** (see Topic 4.3) **Graphic Organizer** (see Topic 4.7)

			means with the details about the populations it represents in the context of the study.	
	4.G Justify a claim based on statistical inference method results	4.8.B Justify a claim based on a confidence interval for the difference between two population means	4.8.B.1 A confidence interval for the difference between two population means provides an interval of values that may serve as convincing evidence to support a particular claim about the difference in two population means. For example, if the interval contains 0, then there is insufficient evidence to conclude there is a difference between the two population means. If the interval does not contain 0, then there is sufficient evidence to conclude there is a difference between the two population means.	
<u>Day 10</u> *4.9* *Setting Up a Test for the Difference Between Two Population Means*	2.C Identify appropriate statistical inference methods.	4.9.A Identify an appropriate testing method for the difference between two population means including the parameters for the difference between the two population means	4.9.A.1 The appropriate test for the difference between two population means is a twosample t-test for a difference between two population means. 4.9.A.2 The parameters for a hypothesis test for the difference between two population means should reference the population parameters, the response variables, and the populations in context.	**Round Table** (see Topic 4.3)
	2.E Identify the null and alternative hypotheses.	4.9.B Identify the null and alternative hypotheses for the difference between two population means.	4.9.B.1 The null hypothesis for a two-sample t-test for the difference between two population means, μ_1 and μ_2, can be written as either $H_0: \mu_1 - \mu_2 = 0$ or $H_0: \mu_1 = \mu_2$. A one-sided alternative hypothesis for the difference between population means can be written as either $H_a: \mu_1 < \mu_2$ (or equivalently $H_a: \mu_1 - \mu_2 < 0$ or $H_a: \mu_1 > \mu_2$ (or equivalently $H_a: \mu_1 - \mu_2 > 0$). A two-sided alternative hypothesis for the difference between population means can be written as $H_a: \mu_1 \neq \mu_2$ (or equivalently $H_a: \mu_1 - \mu_2 \neq 0$).	
	4.E Justify the use of a chosen statistical inference method by verifying conditions.	4.9.C Justify the appropriateness of a hypothesis test for the difference between two population means by verifying conditions.	4.9.C.1 A two-sample t-test for a difference between population means requires that three conditions be met: 4.9.C.1.i The randomization condition—the data should be collected using two independent random samples or a randomized experiment. 4.9.C.1.ii The 10% condition—when sampling	

			without replacement, the size of each sample should be less than or equal to 10% of the respective population size: $n_1 \leq 10\% N_1$ and $n_2 \leq 10\% N_2$, where N_1 is the size of population 1 and N_2 is the size of population 2. The sample sizes are represented as n_1 and n_2. (Note: This condition is unnecessary when the data are from a randomized experiment.) 4.9.C.1.iii The sample data condition—both samples should have a sample size greater than or equal to 30 or it is indicated that both population distributions are approximately normal. If either sample size is less than 30, both sample data distributions should be free from strong skewness and outliers.	
Day 11 *4.10 Carrying Out a Test for the Difference Between Two Population Means*	3.E Calculate appropriate statistical inference method results.	4.10.A Calculate an appropriate test statistic and p-value for testing a hypothesis for the difference between two population means.	4.10.A.1 The test statistic for a two-sample t-test for the difference between two population means is $t = \frac{(\bar{x}_1 - \bar{x}_2) - 0}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$. The t-statistic has a t-distribution when the null hypothesis is true. The t-statistics with the degrees of freedom can be found using technology. The degrees of freedom fall between $n_1 + n_2 - 2$ and the smaller of $n_1 - 1$ and $n_2 - 1$. 4.10.A.2 The p-value for a two-sample t-test for the difference between two population means can be found using the appropriate t-distribution table or from the appropriate t-distribution using technology	**Round Table** (see Topic 4.3)
	4.F Interpret results of statistical inference methods.	4.10.B Interpret the p-value of a hypothesis test for the difference between two population means	4.10.B.1 The p-value is the probability of obtaining a test statistic as extreme or more extreme than the test statistic that was observed (i.e., in the direction of the alternative hypothesis) given that the null hypothesis is true. An interpretation of the p-value of a hypothesis test for a two-sample test for the difference between two population means should include a statement that the p-value is computed by assuming that the null hypothesis is true (i.e., by assuming the population means are equal to each other in context).	
	4.G Justify a claim based	4.10.C Justify a claim about	4.10.C.1 A formal decision explicitly compares	

	on statistical inference method results.	the populations based on the results of a hypothesis test for the difference between two population means.	the p-value to the significance level, α. If the p-value ≤α , then reject the null hypothesis, $H_0: \mu_1 - \mu_2 = 0$ or $H_0: \mu_1 = \mu_2$. If the p-value >α, then fail to reject the null hypothesis. 4.10.C.2 The results of a hypothesis test for a twosample t-test for a difference between two population means can serve as the statistical reasoning to support the answer to an investigative question about the two populations that were sampled. 4.10.C.3 A conclusion for the hypothesis test for the difference between two population means is stated in context consistent with, and in terms of, the alternative hypothesis using nondefinitive language. The conclusion should contain a reference to the parameters and the populations.	
Day 12	**Unit Test: AP Progress Check 4**			

Unit Title	
Unit 5: Regression Analysis	
Relevant Standards: Bold indicates priority	
3.A, 3.B, 4.A, 4.B, 4.D	
Essential Question(s)	**Enduring Understanding(s)**
• Does the fact that the number of shark attacks increases as ice cream sales increase necessarily mean that ice cream sales cause shark attacks? • How can we determine the effectiveness of a linear model that uses the number of cricket chirps per minute to predict temperature?	• Regression models describe and quantify relationships between quantitative variables. • Correlation and regression can identify patterns and support prediction but do not establish causation. • Residual analysis helps determine whether a model appropriately represents the data. • Statistical inference can be used to evaluate the strength and significance of relationships.
Demonstration of Learning	**Pacing for Unit**

Progress Check 5
• Multiple-choice: ~19 questions
• Free-response: 2 questions
  ○ Question 1: Multi-Focus on Practices 2, 3, and 4
  ○ Question 2: Multi-Focus on Practices 2, 3, and 4
 	
The additional online question bank will be used to create a mid-unit quiz and other checks for understanding throughout the unit.
 	
College Board AP Exam
Section I MCQ Weighting: 10–20%
• Descriptive Bivariate Data: Interpreting scatterplots for direction, form, strength, and unusual features.
• Least-Squares Regression Line (LSRL): Calculating and interpreting the slope, y-intercept, standard deviation of residuals, and coefficient of determination.
• Residual Analysis: Calculating residuals, interpreting residual plots to assess model linearity, and identifying influential points vs. outliers
 	
See AP Exam Overview for more information
	7 Block Periods
	
	NOTE:
	Midterm & AP Exam Review / Mock Exams - 11 Blocks
	Flexibility/Buffer/Post-AP Exam Project - 6 Blocks

Family Overview (link below)	**Integration of Technology:**
AP Statistics FAMILY MATERIALS	• Create scatterplots and regression models using graphing calculators and Desmos. • Calculate and interpret correlation and regression statistics. • Use regression output generated by calculators and software. • Conduct inference for regression parameters using graphing calculators and Desmos.. • Evaluate model fit using technology.
Unit-specific Vocabulary	**Aligned Unit Materials, Resources, and Technology (beyond core resources)**
Scatterplot Association Linear relationship Correlation Correlation coefficient (r) Residual Residual plot Explanatory variable Response variable Coefficient of	www.mathmedic.com www.desmos.com www.stapplet.com https://skewthescript.org/

Regression Least-squares regression line Slope Intercept Predicted value	determination (r^2) Extrapolation Influential point Outlier Model fit Inference for slope

Opportunities for Interdisciplinary Connections:	Anticipated misconceptions
• Science: modeling relationships among variables. • Economics: forecasting and trend analysis. • Business: sales and marketing analytics. • Environmental Science: climate and ecological modeling. • Sports Analytics: performance prediction and evaluation.	1. Assuming correlation implies causation or using correlation to evaluate non-linear relationships. 2. Using deterministic language rather than estimated/predicted language when interpreting slope and y-intercept. 3. Relying solely on a high R^2 value to assess model fit instead of checking for randomness in a residual plot. 4. Confusing high-leverage points, outliers, and influential points in bivariate data. 5. Reading statistics from the intercept/constant row instead of the predictor variable row on computer software printouts during slope inference.
Connections to Prior Units	**Connections to Future Units**
• Builds on graphical analysis and association concepts from Unit 1. • Uses probability and inference concepts from Units 2–4. • Requires interpretation of variability and statistical significance.	Provides foundational preparation for college statistics, data science, economics, social science research, and STEM fields.

Differentiation through *Universal Design for Learning*

	Engagement	Representation	Action & Expression
2.A	"Parameter vs. Statistic Treasure Hunt" sorting prompt information into population parameters vs. sample statistics across polling and manufacturing scenarios.	Color-coded visual decoder mapping population parameters alongside corresponding sample statistics and sample sizes (n, N).	Annotate AP-style prompts using digital highlighters or tags to isolate parameters, statistics, and sample sizes.
2.C	"Model Matcher" challenge determining whether a scenario requires the sampling distribution of a proportion, difference in proportions, mean, or difference in means.	Flowchart decision tree categorizing sampling distribution models by variable type (categorical vs. quantitative) and group count (1 vs. 2 samples).	Construct a visual selection flowchart or record an audio walkthrough classifying sampling distribution models for 3 unlabelled scenarios.
3.A	"Penny Sampling Lab" physically drawing repeated sample means/proportions to build an empirical sampling distribution dotplot on a wall grid.	Visual progression chart illustrating Population Distribution \to Individual Sample Distributions \to Sampling Distribution of the Statistic.	Generate empirical sampling distributions using technology and export labeled graphs.
3.B	"Sample Size Effect Lab" calculating how changing n compresses standard error while keeping the mean centered at the true population parameter.	Formula reference card for sampling distribution parameters (\mu_{\hat{p}} = p, \sigma_{\hat{p}} = \sqrt{\frac{p(1-p)}{n}}, \mu_{\bar{x}} = \mu, \sigma_{\bar{x}} = \frac{\sigma}{\sqrt{n}}) and z-scores (z = \frac{\text{stat} - \text{param}}{\text{SE}}).	Calculate means, standard deviations, and z-scores for sampling distributions via worked calculation sheets, calculator steps, or video walkthroughs.
3.E	"Quality Assurance Escape Room" computing tail probabilities under sampling distribution models to pass inspection checkpoints.	Step-by-step workflow displaying z-score transformations and Normal distribution curve shading alongside calculator syntax (normalcdf).	Submit a probability calculation portfolio featuring both handwritten standard error calculations and software/calculator outputs.

4.A	"Three Distributions Sorting Challenge" placing population distributions, single sample distributions, and sampling distributions side-by-side to contrast shape, center, and spread.	Comparative anchor chart illustrating how sampling distribution variability decreases by \frac{1}{\sqrt{n}} compared to population variability.	Deliver a written comparison essay or audio podcast detailing structural differences between a population distribution and its sampling distribution.
4.B	"Unbiased Estimator Debate" testing whether sample medians vs. sample means center at the true population center across simulated samples.	Bullseye graphic displaying high vs. low bias (center alignment) and high vs. low variability (spread width).	Write a Claim-Evidence-Reasoning (CER) justification evaluating whether a given sample statistic serves as an unbiased estimator of a parameter.
4.D	"Auditor Briefing" interpreting standard error to non-technical executives seeking to understand expected sample-to-sample fluctuation.	Sentence-stem bank providing mandatory AP formulaic phrasing for interpreting $\sigma_{\hat{p}}$ and $\sigma_{\bar{x}}$ in context.	Write an executive audit memo or record a client briefing explaining the contextual meaning of standard error for a quality control metric.
4.E	"Condition Auditor" checking whether sample size is large enough for the Central Limit Theorem or Large Counts and verifying 10\% independence.	Visual condition checklist featuring icons for Randomness, 10% Condition, and Normality/CLT rules.	Produce a "Sampling Model Verification Report" detailing mathematical proofs verifying or refuting model conditions for a given dataset.
4.F	"Plausible Outcome Investigator" translating calculated sampling probabilities into plain-language assessments of how likely a sample result is under an assumed parameter.	Template guide providing standardized AP sentence frameworks: *"Assuming [true parameter], the probability of getting a sample statistic of [observed value] or more extreme is [probability]."*	Record an audio segment or write an explanatory analysis explaining what a sampling distribution probability output means in plain English.
4.G	"Is the Manufacturer Lying?" using sampling distribution probabilities as evidence to determine if a company's claimed parameter is credible.	Decision tree linking low sampling probabilities (P < 0.05) to rejecting parameter claims due to convincing sample evidence.	Write a formal CER justification essay or deliver a presentation verifying or refuting a parameter claim using sampling distribution calculations.

Supporting Multilingual/English Learners (*CELP standards*)

	Emerging	Expanding	Bridging
2.A	Identify response variable (y) and explanatory variable (x) from a scatterplot using color-coded axis labels.	Extract slope , y-intercept, r, r^2, and s from a computer regression output table using a graphic key.	Parse bivariate regression problem descriptions, identifying explanatory/response variables, transformation needs, and regression output parameters.
2.C	Match "Scatterplot / Slope" scenario cards to *Linear Regression t-test for Slope* using visual cards.	Identify when to use inference for slope vs. descriptive regression modeling using a decision flowchart.	Distinguish between descriptive bivariate analysis, linear regression slope t-inference, and non-linear model transformations.
3.A	Plot points (x, y) on a scatterplot grid and draw an estimated line of best fit using visual alignment guides.	Construct scatterplots and residual plots from two-variable quantitative data sets using step-by-step graphing templates.	Construct scatterplots, residual plots, and transformed plots, verifying linear pattern fit.
3.B	Calculate predicted values by plugging given x-values into a provided regression equation,	Calculate predicted values, residuals, slope, and r^2 using formula templates.	Calculate LSRL equations, residuals, standard error of slope, and transformed regression models using mathematical formulas and technology.
3.E	Identify the t-statistic for slope and corresponding p-value from a computer output table using a highlighter key.	Calculate test statistics and confidence intervals for slope using computer output and formula guides.	Independently compute t-test statistics, p-values, and t-confidence intervals for population regression.
4.A	Describe scatterplot direction (positive/negative) and form (linear/non-linear) using visual vocabulary cards.	Describe scatterplots using **D.O.F.S.** (*Direction, Outliers, Form, Strength*) in context using sentence frames.	Compare multiple bivariate relationships using D.O.F.S., r, r^2, and s, explaining context and influential points.
4.B	Complete claim statements about linear association strength based on r values.	Justify whether a linear model is appropriate using residual plot patterns (*no pattern = linear model appropriate*) and r^2 templates.	Construct rigorous arguments justifying linear model appropriateness or non-linear transformation needs based on residual plots and r^2.

4.D	Match slope and y-intercept definition cards to their contextual meanings in a sample regression line.	Interpret slope (b), y-intercept (a), r^2, and s in context using structured sentence frames ("*For every 1 unit increase in x...*").	Interpret slope, y-intercept, r^2, standard deviation of residuals s, and SE in complex real-world scientific contexts.
4.E	Check off slope t-inference conditions **L.I.N.E.** (*Linear, Independent, Normal residuals, Equal variance*) on a visual condition checklist card.	Verify slope inference conditions (L.I.N.E.) using provided residual plots and histograms with sentence starters.	Evaluate L.I.N.E**.** conditions using scatterplots, residual plots, and histograms.
4.F	Complete a confidence interval interpretation frame for slope: "*We are 95% confident that for each 1 [unit x], the true mean [variable y] increases by...*"	Interpret confidence intervals for slope \beta_1 and p-values for slope t-tests in context using structured sentence frames.	Interpret confidence intervals and hypothesis tests for slope \beta_1 in context, articulating the relationship between variables.
4.G	Circle "Linear Relationship Exists" or "No Linear Relationship" based on p-value vs. \alpha = 0.05 cards.	Write formal conclusions regarding linear relationships using decision templates ("*Because p-value < \alpha, we have evidence of a linear relationship...*").	Formulate comprehensive statistical arguments regarding linear association between two quantitative variables based on regression slope inference.

Unit Outline

Lesson Sequence	Skills	Learning Objective	Essential Knowledge	AP Activities *(if available)*
Day 1 *5.1 Graphical Representations Between Two Quantitative Variables*	3.A Construct tabular and graphical representations of data and distributions.	5.1.A Construct scatterplots depicting the relationship between two quantitative variables.	5.1.A.1 A bivariate quantitative data set consists of observations of ordered pairs from two quantitative variables, collected from the same individuals in a sample or population, and can be used to construct a scatterplot. 5.1.A.2 A scatterplot shows the relationship between two quantitative variables for each observation, one corresponding to the value on the x-axis and one corresponding to the value on the y-axis. The explanatory variable is placed on the x-axis and is the variable whose values are used to explain or predict the corresponding values for the response variable, which is placed on the y-axis.	**Sketch and Switch** Ask students to create a sketch of a scatterplot using a prompt such as a "weak negative, non-linear association." Then have them switch papers to review each other's work. **Team Challenge** (see Topic 5.2) **Relief Pitcher** (see Topic 5.5)
	4.A Describe and compare tabular and graphical representations of data, as well as summary statistics.	5.1.B Describe the characteristics of a scatterplot.	5.1.B.1 A description of the association shown in a scatterplot includes form, direction, strength, and unusual features. 5.1.B.2 The form of the association shown in a scatterplot, if any, can be described as linear or non-linear. 5.1.B.3 The direction of the association shown in a scatterplot, if any, can be described as positive or negative. A positive association means that as values of the explanatory variable increase, the values of the response variable tend to increase. A negative association means that as values of the explanatory variable increase, the values of the response variable tend to decrease. 5.1.B.4 The strength of the association shown in a scatterplot is how closely the points	

			follow the general pattern. Strength can be described as strong, moderate, or weak. 5.1.B.5 Unusual features of a scatterplot include clusters of individual points or points that don't fit in the general pattern of association between the two variables.	
	4.B Justify a claim based on statistical calculations and results.	5.1.C Justify a claim using scatterplots depicting the relationship between two quantitative variables.	5.1.C.1 Scatterplots depicting the relationship between two numeric variables may reveal information that can be used to justify claims about the variable in context.	
<u>Day 2</u> *5.2* *Correlation*	4.D Interpret statistical calculations and results to assess meaning or a claim.	5.2.A Interpret the correlation for a linear relationship	5.2.A.1 The correlation coefficient, r, summarizes the strength and direction of the linear association between two quantitative variables. The correlation coefficient r is unit-free and always between −1 and 1, inclusive. A negative correlation coefficient value indicates a negative association, and a positive correlation coefficient value indicates a positive association. 5.2.A.2 The strength of the linear association is determined by how close the correlation coefficient is to −1 or 1. A value of r = 0 indicates that there is no linear association. A value of r =-1 or r =1 indicates that there is a perfect linear association. 5.2.A.3 A correlation coefficient close to −1 or 1 does not necessarily mean that a linear model is appropriate. 5.2.A.4 A perceived or real relationship between two variables does not mean that changes in one variable cause changes in the other. That is, correlation does not necessarily imply causation.	**Team Challenge** Set up teams of three or four and task students with solving different multiple-part problems in Unit 5 with different datasets to answer investigative questions. Have teams explain their work to other teams. **Relief Pitcher** (see Topic 5.5)
<u>Day 3</u> *5.3* *Linear Regression Models*	3.B Calculate summary statistics, relative positions of points within a distribution, and predicted responses.	5.3.A Calculate a predicted response value using a linear regression model.	5.3.A.1 If the form of the relationship between x and y appears linear, we can approximate the relationship between x and y using a linear regression model, which is a linear equation that uses an explanatory variable, x, to predict the response variable, y. 5.3.A.2 In a linear regression model, the predicted response value, denoted by $\hat{y}$, is calculated as $\hat{y} = a + bx$, where a is the y-intercept, b is the slope of the regression line, and x is the explanatory variable. 5.3.A.3 Extrapolation is predicting a response value using a value for the explanatory	**Think-Aloud** Have students toss a handful of coins and record how many land heads up. This is trial 1. Then have them remove the coins that landed heads up. For trial 2, have students toss the remaining coins (i.e., the coins left over after removing those that landed heads up) and record how many land heads up on the second toss. Ask students to think about the trend and make a prediction, discussing their ideas

			variable that is beyond the interval of x-values used to determine the regression line. The predicted value is less reliable the further the estimate is extrapolated. 5.3.A.4 Interpolation is predicting a response value using a value for the explanatory variable that is within the interval of x-values used to determine the regression line.	with a partner. Will it be linear? A scatterplot of many trials should show a nonlinear relationship. **Team Challenge** (see Topic 5.2) **Relief Pitcher** (see Topic 5.5)
Day 4	**Mid-Unit Assessment**			
Day 5 *5.4* *Residuals*	3.B Calculate summary statistics, relative positions of points within a distribution, and predicted responses.	5.4.A Calculate the differences between the observed and predicted values.	5.4.A.1 A residual is the difference between the observed response value and the predicted response value for the given value of the explanatory variable: $residual = y - \hat{y}$ or (residual - observed y -predicted y).	**Reversing Interpretations** Instead of asking students to interpret a residual, give them the residual and the equation of the least-squares regression line and ask them to make a prediction for a particular observation (e.g., "One wolf in the pack had a length of 14. m and a residual of −98. 7. What does that −98. 7 tell us about that particular wolf?") **Team Challenge** (see Topic 5.2) **Relief Pitcher** (see Topic 5.5)
	4.D Interpret statistical calculations and results	5.4.B Interpret the differences between the observed and predicted values.	5.4.B.1 If the residual is positive, the model underpredicts (underestimates) the value of the response variable. If the residual is negative, the model overpredicts (overestimates) the value of the response variable.	
	4.A Describe and compare tabular and graphical representations of data, as well as summary statistics.	5.4.C Describe the form of association of bivariate data using residual plots.	5.4.C.1 A residual plot is a scatterplot of the residuals versus the predicted response values (or the explanatory variable values). 5.4.C.2 Residual plots can be used to investigate the appropriateness of the linear regression model for the observed data. 5.4.C.3 The linear regression model should only be fit to the data if the data exhibit a linear trend. Apparent randomness in a residual plot for a linear regression model is confirmation of a linear form in the association between the two variables and indicates that the simple linear regression model is an appropriate model for the data. 5.4.C.4 Curvature in the residual plot for a linear	

			regression model suggests that the linear model is not the most appropriate model for the data.	
Day 6 *5.5 Least-Squares Regression*	3.B Calculate summary statistics, relative positions of points within a distribution, and predicted responses.	5.5.A Calculate the coefficients for the least-squares regression line model.	5.5.A.1 The simple linear regression model is fit to the data by minimizing the sum of the squares of the residuals. Because of this, the resulting equation is often called the least-squares regression line (LSRL) and is calculated using technology. This regression line will pass through the point $(\bar{x}, \bar{y})$. 5.5.A.2 The slope of the regression line, b, is calculated using technology. 5.5.A.3 The y-intercept of the regression line, a, is calculated using technology. 5.5.A.4 In simple linear regression, the correlation coefficient, r, is calculated using technology. 5.5.A.5 In simple linear regression, the square of the correlation coefficient, r^2, is called the coefficient of determination. The value of r^2 is the proportion of variation in the response variable that is explained by the linear relationship with the explanatory variable.	**Relief Pitcher** Use this strategy to review multiple concepts at the end of a unit or to spiral review at the end of the course. For instance, when reviewing for the Unit 5 test, students can earn 5 points if they get a question correct when up at the "pitcher's mound" and 3 points if they do not know the answer but their team in the "bullpen" helps them answer it. **Team Challenge** (see Topic 5.2) **Relief Pitcher** (see Topic 5.5)
	4.D Interpret statistical calculations and results to assess meaning or a claim.	5.5.B Interpret coefficients for the least-squares regression line model.	5.5.B.1 The coefficients of the least-squares regression line model (line of best fit) are the slope, b, and the y-intercept, a, because they are based on a sample of values. 5.5.B.2 The slope of the least-squares regression line can be interpreted as the predicted increase or decrease in the response variable for a oneunit increase in the explanatory variable, and it should be interpreted in context. 5.5.B.3 The y-intercept in the least-squares regression line is the predicted value of the response variable when the explanatory variable is equal to 0, and it should be interpreted in context. Sometimes, the y-intercept of the line does not have a reasonable interpretation in context because x = 0 might be beyond the interval of x-values used to determine the regression line (extrapolation). At other times, the y-intercept of the line does not have a logical interpretation in context because it might be a negative value for a response variable that has no negative values, such as height	
Day 7	**Unit Test: AP Progress Check 4**			

Section I: Multiple-Choice Questions (MCQs)
42 Questions | 90 Minutes | 50% of Exam Weight

In addition to content units, multiple-choice questions across the exam are explicitly mapped to the four Statistical Practices:

Statistical Practice	Description	MCQ Exam Weighting
Practice 1: Formulate Questions	Identify valid statistical questions requiring data investigation.	5–10%
Practice 2: Collect Data	Identify and justify data collection methods, experimental design, and inference procedures.	20–30%
Practice 3: Analyze Data	Construct graphs, calculate summary statistics, probabilities, standard errors, and test results.	25–35%
Practice 4: Interpret Results	Interpret statistical outputs, evaluate claims, check inference conditions, and communicate conclusions in context.	25–35%

Section II: Free-Response Questions (FRQs)
4 Questions | 90 Minutes | 50% of Exam Weight

Equal-weighted multi-part free-response questions (10 points each):
1. Question 1 (Multi-Focus)
   Primary focus on Practices 1 & 2 (Formulating Questions & Data Collection / Experimental Design).
2. Question 2 (Multi-Focus)
   Primary focus on Practices 3 & 4 (Data Analysis & Result Interpretation).
3. Question 3 (Inference Focus)
   Requires completing a formal inference procedure (a Confidence Interval or Hypothesis Test from Unit 3 or Unit 4), including checking conditions, executing calculations, and interpreting results in context.
4. Question 4 (Comprehensive Multi-Focus)
   Integrates Practices 2, 3, & 4 across multiple content units to evaluate deep statistical reasoning.

Course Title	Content Area:	Grade Level:	Credit (if applicable)
AP Chemistry	Science	Gr. 10-12	1.0

Course Description

The AP Chemistry course provides students with a college-level foundation to support future advanced coursework in chemistry. Students cultivate their understanding of chemistry through inquiry-based investigations, as they explore content such as:

- Atomic Structure and Properties
- Compound Structure and Properties
- Properties of Substances and Mixtures
- Chemical Reactions
- Kinetics
- Thermochemistry
- Equilibrium
- Acids and Bases
- Thermodynamics and Electrochemistry

This course requires that 25% of instructional time be spent in hands-on laboratory work, with an emphasis on inquiry-based investigations that provide students with opportunities to demonstrate the foundational chemistry principles and apply the science practices. This includes a minimum of 16 hands-on labs (at least six of which are inquiry based).

Inquiry-based laboratory experiences support the AP Chemistry course and AP Course Audit curricular requirements by providing opportunities for students to engage in the science practices as they design plans for experiments, make predictions, collect and analyze data, apply mathematical routines, develop explanations, and communicate about their work.

Colleges may require students to present their laboratory materials from AP science courses before granting college credit for laboratory work, so students should be encouraged to retain their laboratory notebooks, reports, and other materials.

Aligned Core Resources	Connection to the *BPS Vision of the Graduate*
CollegeBoard Course and Exam Description Students must learn the skills necessary to use the following ordinary equipment: Beakers, flasks, test tubes, crucibles, evaporating dishes, watch glasses, burners, plastic and glass tubing, stoppers, valves, spot plates, funnels, reagent bottles, wash bottles, droppers, and measuring equipment. The list of measuring equipment includes: Balances (single pan, double pan, triple beam), thermometers (°C), barometers, graduated cylinders, burets, volumetric pipets, graduated pipets, volumetric flasks, ammeters, voltmeters, pH meters, and spectrophotometers. A more comprehensive list of laboratory equipment can be found in Appendix C of AP Chemistry Guided Inquiry Experiments: Applying the Science Practices. Microscale Experiments One important change in chemistry lab instruction in recent years has been the introduction of microscale experiments. Teachers can determine whether microscale experiments are appropriate for their students and classroom/lab space. Here are some benefits to consider: • Decreased cost of chemicals acquisition and	

disposal
- Reduced storage space requirements and safer storage
- Less need for elaborate lab facilities in schools
- Greater care needed by students to obtain and observe results
- Shorter experiment times as well as easier and faster cleanup
- Ability to carry out some experiments that were once restricted to demonstration because of their hazards in macroscale

Additional Course Information: ***Knowledge/Skill Dependent Courses/Prerequisites***	**Link to *Completed Equity Audit***
Students should have successfully completed an introductory high school chemistry course and Algebra 2. Grade 10 students may take concurrently with Biology ACC with teacher recommendation and "83" average in Physical Science ACC.	

Standard Matrix

Science Practices & Skills	**Unit 1**	**Unit 2**	**Unit 3**	**Unit 4**	**Unit 5**	**Unit 6**	**Unit 7**	**Unit 8**	**Unit 9**
Science Practice 1: Models and Representations *(Describe models and representations, including across scales.)*									
1.A Describe the components of and quantitative information from models and representations that illustrate particulate-level properties only.	X								
1.B Describe the components of and quantitative information from models and representations that illustrate both particulate-level and macroscopic level properties.				X	X	X			
Science Practice 2: Question and Method *(Determine scientific questions and methods.)*									
2.A Identify a testable scientific question based on an observation, data, or model.	X								
2.B Formulate a hypothesis or predict the results of an experiment.				X					
2.C Identify experimental procedures that are aligned to a scientific question (which may include a sketch of a lab setup).			X						
2.D Make observations or collect data from representations of laboratory setups or results, while attending to precision where appropriate.						X		X	
2.E Identify or describe potential sources of experimental error.			X						
2.F Explain how modifications to an experimental procedure will alter results.							X		X
Science Practice 3: Representing Data and Phenomenon *(Create representations or models of chemical phenomena.)*									
3.A Represent chemical phenomena using appropriate graphing techniques, including correct scale and units.		X				X	X		
3.B Represent chemical substances or phenomena with appropriate diagrams ormodels(e.g.,electronconfiguration).		X		X	X				
3.C Represent visually the relationship			X				X		

between the structures and interactions across multiple levels or scales (e.g., particulate to macroscopic).									
Science Practice 4: Model Analysis *(Analyze and interpret models and representations on a single scale or across multiple scales.)*									
4.A Predict and/or explain chemical properties or phenomena (e.g., of atoms or molecules) using given chemical theories, models, and representations.	X		X						
4.B Explain whether a model is consistent with chemical theories.	X								
4.C Explain the connection between particulate-level and macroscopic properties of a substance using models and representations.	X	X	X						
4.D Explain the degree to which a model or representation describes the connection between particulate-level properties and macroscopic properties.			X				X		X
Science Practice 5: Mathematical Routines *(Solve problems using mathematical relationships)*									
5.A Identify quantities needed to solve a problem from given information (e.g., text, mathematical expressions, graphs, or tables).	X					X	X		
5.B Identify an appropriate theory, definition, or mathematical relationship to solve a problem. when one variable changes.	X				X		X	X	
5.C Explain the relationship between variables within an equation			X	X	X		X	X	
5.D Identify information presented graphically to solve a problem.	X							X	
5.E Determine a balanced chemical equation for a given chemical phenomenon.				X	X				
5.F Calculate, estimate, or predict an unknown quantity from known quantities by selecting and following a logical computational pathway and attending to precision (e.g., performing dimensional analysis and attending to significant figures).			X			X	X	X	X
Science Practice 6: Argumentation *(Develop an explanation or scientific argument.)*									
6.A Make a scientific claim.		X							
6.B Support a claim with evidence from experimental data.				X					
6.C Support a claim with evidence from representations or models at the particulate level, such as the structure of atoms and/or molecules.		X						X	X
6.D Provide reasoning to justify a claim using chemical principles or laws, or using mathematical justification.						X	X	X	X
6.E Provide reasoning to justify a claim using connections between particulate and macroscopic scales or levels.			X		X	X			X
6.F Explain the connection between experimental results and chemical concepts, processes, or theories.							X		
6.G Explain how potential sources of experimental error may affect the experimental results.								X	

Unit Links
Unit 1: Atomic Structure and Properties Unit 2 : Compound Structure and Properties Unit 3: Properties of Substances and Mixtures Unit 4: Chemical Reactions Unit 5: Kinetics Unit 6: Thermochemistry Unit 7: Equilibrium Unit 8: Acids and Bases Unit 9: Thermodynamics and Electrochemistry

Unit Title:

Unit 1: Atomic Structure and Properties

Relevant Standards: Bold indicates priority

1.1 Moles and Molar Mass: Students can convert between mass, moles, and number of particles using Avogadro's number, and determine molar mass from chemical formulas to support stoichiometric calculations.

1.2 Mass Spectroscopy of Elements: Students can interpret mass spectra to determine isotopic composition and calculate average atomic mass using weighted isotopic abundances.

1.3 Elemental Composition of Pure Substances: Students can calculate percent composition and determine empirical formulas from experimental or compositional data.

1.4 Composition of Mixtures: Students can determine the composition of mixtures using mass or percent data and distinguish mixtures from pure substances based on quantitative particle-level information.

1.5 Atomic Structure and Electron Configuration: Students can determine subatomic particles and represent isotopes using nuclear notation, and write electron configurations and orbital diagrams using the Aufbau principle, Hund's rule, and the Pauli exclusion principle.

1.6 Photoelectron Spectroscopy (PES): Students can interpret PES data to determine electron configurations and relate peak positions to electron energy levels and sublevels.

1.7 Periodic Trends: Students can predict and explain periodic trends in atomic radius, ionization energy, and electronegativity using effective nuclear charge, shielding, and electron configuration.

Essential Question(s):	**Enduring Understanding(s):**
1. How can the same element be used in nuclear fuel rods and fake diamonds? 2. How can large quantities of objects be counted by weighing? 3. If atoms are too small to be observed directly, how do we know how they're structured? 4. Why does the periodic table have the shape that it does?	1. The arrangement of electrons in atoms determines the structure of the periodic table and influences the chemical behavior of elements. 2. Coulombic attractions between charged particles explain trends in atomic size, ionization energy, and electronegativity. 3. Atomic models are supported by experimental evidence and are used to explain the behavior of matter at the subatomic level. 4. The composition of matter can be represented and quantified using atomic theory, isotopes, and the mole concept. 5. Periodic trends arise from predictable patterns in electron configuration and effective nuclear charge.
Demonstration of Learning:	**Pacing for Unit**
• Success with Unit 1 MCQs and FRQs via AP Classroom • Analysis of a Hydrate Lab • Constant Composition of SG Lab • Separation of a Mixture Lab • Quizzes (AP Classroom MCQs and FRQs) every few topics • Electron POGIL • Progress Check 1 from AP Classroom Unit 1 is 7–9% AP Exam Weighting See AP Exam Description	15 days of instruction 3 lab days 2 days of review / assessment
Family Overview (link below)	**Integration of Technology:**
AP Chemistry FAMILY MATERIALS	*N/A*

Unit-specific Vocabulary:	Aligned Unit Materials, Resources, and Technology (beyond core resources):
element, atom, molecule, compound, chemical formula, formula unit, mixture, homogeneous mixture (solution), heterogeneous mixture, pure substance, atomic number, mass number, isotope, isotopic abundance, average atomic mass, mole, molar mass, avogadro's number (6.022×10^{23}), empirical formula, molecular formula, hydrate, anhydrous, percent composition, electron, proton, neutron, nuclear notation, atomic orbital, s, p, d, f orbitals, electron configuration, aufbau principle, pauli exclusion principle, hund's rule, photoelectron spectroscopy (PES), ionization energy, electronegativity, atomic radius, ionic radius, effective nuclear charge, shielding effect, periodic trends	• Bunsen burners • General lab equipment
Opportunities for Interdisciplinary Connections:	**Anticipated misconceptions:**
• Physics: electromagnetic radiation, photoelectron spectroscopy, Coulombic attraction • Mathematics: scientific notation, dimensional analysis, logarithmic relationships • Engineering: materials design based on atomic properties • Earth Science: isotopes and radioactive dating • History of Science: development of atomic models and quantum theory	Ability to identify periodic trends but difficulty explaining why these trends occur
Connections to Prior Units:	**Connections to Future Units:**
• Structure of the atom introduced in middle school, physical science, and biology • Build upon initial model (likely Bohr model) by introducing quantum view of the atom (orbitals)	• Moles and molar mass is used throughout the curriculum (stoichiometry) • Periodic trends explain reactivity (Unit 4) • Valence electrons dictate bonding (Unit 2)

Differentiation through *Universal Design for Learning*

	Engagement	Representation	Action & Expression
LT1	"Mole Day Estimation Challenge" estimating particles in everyday objects (e.g., drops of water, aluminum cans).	Color-coded dimensional analysis "train tracks" showing unit cancellation and Avogadro's constant	Solve multi-step mole conversions using a choice of digital spreadsheets, handwritten factor-label steps, or video walkthroughs.
LT2	Interactive Mass Spectrometry simulation (e.g., PhET) adjusting isotope abundances to observe shifts in average atomic mass.	Annotated mass spectrum graphs showing peak heights (relative abundance) vs. m/z ratios alongside weighted average formulas.	Calculate average atomic mass from raw spectrum data and present a written or video breakdown identifying unknown elements.
LT3	"Chemical Forensics Mystery" analyzing unknown powder samples from a simulated crime scene to deduce chemical formulas.	Flowchart guide detailing the empirical formula algorithm	Submit empirical/molecular formula calculations via step-by-step problem sets or record a screencast explaining the mole ratio logic.
LT4	"Salad Dressing / Alloy Analysis" determining mass percent of active components in commercial mixtures (e.g., brass, hydrated salts).	Visual pie charts and part-over-whole mass fraction diagrams	Write a laboratory analysis report or construct a visual infographic detailing the separation and mass percentage determination of a mixture.
LT5	"Orbital Hotel" filling game where electrons are guests following hotel rules (Aufbau, Pauli exclusion, Hund's rule).	Color-coded Periodic Table mapping s, p, d, f blocks alongside arrow energy level diagrams and noble gas shorthand notation.	Write full and condensed electron configurations using a choice of interactive orbital board applets, whiteboards, or audio explanations.
LT6	"PES Peak Detective" matching simulated Photoelectron Spectroscopy (PES) graphs to mystery elements based on binding energy.	Dual-display visual showing PES energy plots (X-axis: binding energy decreasing; Y-axis: peak height/number of electrons) aligned to shell models.	Annotate a PES spectrum identifying shell configurations and record a video explaining how nuclear charge shifts binding energy.

LT7	Interactive periodic trend heatmap exploration analyzing atomic radius, ionization energy, electron affinity, and electronegativity.	Graphic organizers comparing nuclear charge, shielding, and effective nuclear charge across periods and down groups.	Draft a Claim-Evidence-Reasoning (CER) justification or record a presentation explaining periodic trend anomalies (e.g., N vs. O first IE).
LT8	Video analysis of alkali metals reacting with water, contrasting reactivity rates down Group 1.	Comparative visual chart mapping valence electron loss/gain ease to ionization energy and electron affinity across families.	Write a comparative reactivity report or record a podcast explaining why reactivity trends differ between metals and nonmetals.

Supporting Multilingual/English Learners (*CELP standards*)

	Emerging	Expanding	Bridging
LT1	Complete dimensional analysis setups using visual cards and color-coded conversion factor templates (grams -> moles -> particles).	Calculate moles, mass, and particle counts using multi-step calculation frames and conversion equation starters.	Perform complex dimensional analysis calculations independently, writing full justifications for unit cancellation and significant figures.
LT2	Identify peak height as "abundance" and peak position as "mass" on a labeled mass spectrum diagram using a word bank.	Explain how average atomic mass is calculated from peak heights and mass positions using cause-and-effect sentence starters.	Calculate fractional abundances and average atomic masses from raw mass spectra data, providing complete written justifications.
LT3	Fill in a structured 4-column empirical formula table (Element -> Mass -> Moles -> Ratio) with formula hints.	Determine empirical formulas using guided calculation steps and sentence frames ("*The mole ratio of X to Y is...*").	Calculate empirical and molecular formulas from percent composition or combustion analysis data with full written explanations.
LT4	Identify pure substances versus mixtures using particulate diagrams and color-coded element/compound cards.	Calculate mass percent of a compound in a mixture using guided calculation frames and explanatory prompts.	Analyze indirect mass composition data (e.g., gravimetric analysis) to determine mixture purity and justify results in writing.
LT5	Fill in orbital energy diagrams (boxes with arrows) using visual rules (Aufbau, Pauli, Hund) and electron configuration word banks.	Write noble gas shorthand electron configurations for atoms and ions using an annotated periodic table guide.	Predict and explain ground-state electron configurations and anomalous exceptions (e.g., Cr, Cu) using formal orbital theory.
LT6	Label PES axes (Binding Energy vs. Relative Number of Electrons) and match peaks to specific subshells using color-coded orbital diagrams.	Explain how peak height relates to electron count and peak position relates to nuclear attraction using comparative sentence frames.	Interpret complex PES data to identify unknown elements, justify subshell binding energy shifts, and explain shielding effects.
LT7	Circle atomic radius or ionization energy trends on a periodic table map using simple directional arrows and visual cues.	Explain trends (atomic radius, ionization energy, electronegativity) using claim-evidence-reasoning (CER) sentence frames ("*As you go across a period...*").	Justify periodic trends and exceptions (e.g., N vs. O ionization energy) using effective nuclear charge (Zeff) and Coulomb's law.
LT8	Sort metals and nonmetals into high/low reactivity categories using a color-coded periodic table.	Explain reactivity trends of alkali metals and halogens using guided paragraph templates incorporating valence electron structure.	Synthesize periodic trends, Zeff, and ionization energy/electron affinity to explain complex reactivity patterns across groups.

Unit Overview

In Unit 1, students will practice identifying components of commonly used models and representations to illustrate chemical phenomena. They will construct models and representations and explain whether they are consistent with chemical theories. Students will also practice translating between data and various representations (e.g., photoelectron spectroscopy data and electron configurations). Students should then be able to use representations (e.g., PES graphs, electron configurations, periodic table, drawings) to explain atomic structure, which is the foundation for all subsequent units. Many of the most useful concepts in chemistry relate to patterns in the behavior of chemical systems, such as periodic trends in atomic and molecular properties. In this unit and all subsequent units, students should learn to analyze data presented graphically to identify patterns and relationships. Once a pattern is identified, students should be able to examine evidence to determine if it supports the pattern or hypothesis pertaining to a testable question.
hypothesis pertaining to a testable question.

Lesson	Learning Target	Success Criteria	Suggested Activities
1.1	**Learning Target 1**	• I can convert between the	**Think-Pair-Share**

Moles and Molar Mass	I can calculate quantities of a substance or its relative number of particles using dimensional analysis and the mole concept.	masses of substances and the actual number of particles using avogadro's number • I can express the mass of an individual atom or molecule in atomic mass units (amu) and understand how it will always be numerically equal to the molar mass of that substance in grams.	Ask students to individually rank three samples in order of increasing number of particles, increasing mass, and increasing mole amounts (Sample A: 1.0 mole of Carbon, SampleB: 18grams of carbon monoxide, SampleC:3.0× 1023 molecules of water). Then have them compare and defend their choices with a partner
1.2 Mass Spectra of Elements	**Learning Target 2** I can explain the quantitative relationship between the mass spectrum of an element and the masses of the element's isotopes.	• I can use the mass spectrum of an element to determine the identity of the isotopes of that element and the relative abundance of each isotope in the sample. • I can determine the average atomic mass of an element from the weighted average of the isotopic masses using the mass of each isotope and its relative abundance.	**Simulations** Conduct a simulation of a mass spectrometer, using a strong magnet and steel ball bearings of various masses, to show students how mass can be used to separate particles based on their ability to be manipulated in an electromagnetic field. Present samples of mass spectra for students to analyze and have them calculate the average atomic mass of an element. Discuss how mass spectrometry could be used to identify the presence of an element within a mixture and the isotopic abundance within an element. Forensic science applications and other modern uses of the technology can be discussed to give relevant context to the concepts.
1.3 Elemental Composition of Pure Substances	**Learning Target 3** I can explain the quantitative relationship between the elemental composition by mass and the empirical formula of a pure substance.	• I can describe the law of definite proportions • I can determine the empirical and molecular formula of a compound given mass data.	**Think-Pair-Share** Have students design an experiment to determine the percent composition of a mixture of sodium carbonate (inert) and sodium bicarbonate. After carrying out the Experiment, provide them with a mock student report to analyze and critique. Then Have them get into pairs and reflect on their particular approach and come up with additional approaches to this problem.
1.4 Composition of Mixtures	**Learning Target 4** I can explain the quantitative relationship between the elemental composition by mass and the composition of substances in a mixture	• I can describe the variable proportion nature of mixtures • I can use data to determine the percent impurity and percent composition of a mixture	**Explore Representations** Translate PES data into an electron configuration and/or predict a PES spectrum based on an element's electron configuration or location in the periodic table. Have students compare their predictions to the actual electron configuration and discuss discrepancies.
1.5 Atomic Structure and Electron Configuration	**Learning Target 5** I can represent the ground-state electron configuration of an atom of an element or its ions using the Aufbau principle	• I can describe the structure of the atom including charge, mass and location of protons, neutrons and electrons • I can use Coulomb's law to describe and compare the force between two charged particles, and therefore the	**Explore Representations** (See 1.4)

		relative amounts of energy to remove different electrons. (related to the distance of the electron from the nucleus and the effective charge of the nucleus ● I can appropriately use the terms "shells (energy levels)" and "subshells (sublevels)," as described by the ground-state electron configuration.Inner electrons are called core electrons, and outer electrons are called valence electrons.	
1.6 Photoelectron Spectroscopy	**Learning Target 6** I can explain the relationship between the photoelectron spectrum of an atom or ion and: i. The Ground-state electron configuration of the species ii. The interactions between the electrons and the nucleus.	I can relate the photoelectron spectroscopy (PES) graph to ● ...the energy required to remove an electron from the corresponding subshell ● ...the number of electrons in that subshell.	**Process Oriented Guided Inquiry Learning (POGIL)** Given ionization energy data from various elements, guide students through a series of questions to help them rationalize the relationship of the charge of the ion to its position on the periodic table, its electronic structure, and reactivity.
1.7 Periodic Trends	**Learning Target 7** I can explain the relationship between trends in atomic properties of elements and electronic structure and periodicity	● I can describe the patterns of recurring properties of the elements, which are explained by patterns of ground-state electron configurations and presence of completely or partially filled shells(and subshells) of electrons in atoms. ● I can follow trends in atomic properties within the periodic table (periodicity) which can be predicted by the position of the element on the periodic table and qualitatively understood using Coulomb's law, the shell model, and the concepts of shielding and effective nuclear charge.	
1.8 Valence Electrons and Ionic Compounds	**Learning Target 8** I can explain the relationship between trends in the reactivity of elements and periodicity	● I can describe the likelihood that two elements will form a chemical bond based on the interactions between the valence electrons and nuclei of the elements. ● I can describe analogous compounds. ● I can describe typical charges of atoms in ionic compounds	
Progress Check 1 ● Multiple-choice: ~20 questions ● Free-response: 2 questions ○ Short ○ Short			

Preparing for the AP Exam
On the AP Exam, students must be able to justify claims with evidence. This starts when students can identify the evidence needed to solve a problem or support a claim and then connect that evidence to known chemical theories. However, many students consistently demonstrated difficulty with this skill. For example, while students can memorize periodic trends, they struggle to explain the electrostatic interactions within an atom that produces period trends as well as exceptions to these trends. Further, students often have difficulty connecting periodic trends to the shell model, Coulomb's law, and elements of quantum theory. To combat these challenges, teachers can ensure that students have a strong foundation in identifying mathematical relationships or patterns from graphical or tabular information and that they can explain how those patterns are consistent with chemical theories and models.

Unit Title:

Unit 2 : Compound Structure and Properties

Relevant Standards: Bold indicates priority

2.1 Types of Chemical Bonds: Students can classify bonds as ionic, polar covalent, or nonpolar covalent based on electronegativity differences and particle-level interactions.

2.2 Intramolecular Force and Potential Energy: Students can explain how bond formation and breaking involve changes in potential energy and stability at the particle level.

2.3 Structure of Ionic Solids: Students can describe the structure of ionic solids as repeating lattices and relate structure to formula ratios and properties.

2.4 Structure of Metals and Alloys: Students can explain metallic bonding using a sea of electrons model and relate structure to conductivity, malleability, and alloy formation.

2.5 Lewis Diagrams: Students can draw Lewis structures for molecules and ions to represent valence electrons and bonding patterns.

2.6 Resonance and Formal Charge: Students can use resonance structures and formal charge calculations to evaluate and compare valid Lewis structures.

2.7 VSEPR and Hybridization: Students can predict molecular geometry and bond angles using VSEPR theory based on electron domain repulsion.

Essential Question(s):	**Enduring Understanding(s):**
1. How are molecular compounds arranged? 2. Why are some bonds easier to break than others? 3. In what ways does a diagram drawn on paper accurately reflect the structure of a molecule? In what ways does it not accurately reflect the structure?	1. The type and strength of chemical bonds (ionic, covalent, metallic) arise from electrostatic interactions between charged particles and determine the structure and properties of substances. 2. Lewis structures and molecular geometry models represent the arrangement of valence electrons and atoms, which can be used to predict bonding, polarity, and molecular shape. 3. The three-dimensional structure of molecules, determined by electron domain repulsion and orbital interactions, directly influences physical and chemical properties. 4. Formal charge and resonance structures provide a framework for evaluating and representing the most accurate depiction of electron distribution in molecules and ions. 5. The polarity of bonds and molecular geometry together determine intermolecular interactions, which influence observable properties such as boiling point, solubility, and phase behavior.
Demonstration of Learning:	**Pacing for Unit**
• Success with Unit 2 MCQs and FRQs via AP Classroom • Quizzes (AP Classroom MCQs and FRQs) every few topics • Using VSEPR to build molecules PhET / with modeling kits • Drawing Lewis Structures practice • Progress Check 2 from AP Classroom Unit 2 is 7–9% of AP Exam Weighting See AP Exam Description	10 instructional days 2 lab days 2 review / assess

Family Overview (link below)	Integration of Technology:
AP Chemistry FAMILY MATERIALS	PhET simulations for Molecular Structure
Unit-specific Vocabulary:	**Aligned Unit Materials, Resources, and Technology (beyond core resources):**
atom, element, compound, mixture, pure substance, law of conservation of mass, law of definite proportions, law of multiple proportions, Dalton's atomic theory, subatomic particle, proton, neutron, electron, atomic number, mass number, isotope, average atomic mass, ion, cation, anion, ionic compound, formula unit, molecular compound, molecule, empirical formula, molecular formula, structural formula, Lewis dot diagram, valence electron, octet rule, exception to the octet rule, expanded octet, incomplete octet, resonance, formal charge, electronegativity, electronegativity trend, polar bond, nonpolar bond, ionic character, Coulombic attraction, crystal lattice, ionic solid, network covalent solid, metallic solid, molecular solid, electron sea model	Molecule modeling kits
Opportunities for Interdisciplinary Connections:	**Anticipated misconceptions:**
• Biology: molecular polarity and hydrogen bonding in DNA and proteins • Physics: electrostatic forces and energy interactions • Materials Science: crystal lattices, semiconductors, metallic properties • Engineering: molecular geometry and material strength • Environmental Science: intermolecular forces in atmospheric chemistry and water systems	• Not accounting for lone pairs when predicting molecular geometry • Not drawing Lewis diagrams correctly– incorrect number of total valence electrons, violating octet rule, not accounting for formal charge when determining most likely structure
Connections to Prior Units:	**Connections to Future Units:**
• Location and number of electrons determines type of bond formed • Number of electrons dictates if cation or anion is formed in an ionic compound	• Type of chemical bond dictates behavior in chemical reaction (unit 4), solubility (3.7, 3.10) • Structure of ionic solids relates to net ionic equations (4.2) • Lewis structures are used throughout the year (i.e. when determining most acidic hydrogen in Unit 8)

Differentiation through *Universal Design for Learning*

	Engagement	Representation	Action & Expression
LT1	Physical testing lab comparing conductivity, melting point, and solubility of unknown solids (ionic, covalent, metallic).	Property comparison matrix mapping electronegativity difference (ΔEN) to bond type and macroscopic physical traits.	Create a flowchart or interactive quiz categorizing unknown compounds into bonding types based on experimental property data.
LT2	"Atomic Spring Simulation" adjusting internuclear distance to plot potential energy wells for single vs. double bonds.	Annotated potential energy vs. internuclear distance graph highlighting equilibrium bond length (well minimum) and bond energy (well depth).	Sketch and defend potential energy curves comparing two diatomics (e.g., H2 vs. O2 or HCl vs. HBr) on whiteboards or digital tools.
LT3	"Crystal Builder Challenge" arranging colored sphere manipulatives to construct 3D ionic lattices while accounting for ionic radii.	Coulomb's Law visual scaffold highlighting how ion charge and size affect lattice energy and cleavage planes.	Build a 3D physical or digital particulate model of an ionic crystal lattice and write a justification referencing Coulombic attraction.
LT4	"Sea of Electrons" simulation exploring why metals conduct electricity and deform without shattering compared to rigid ionic crystals.	Diagrammatic models contrasting pure metals, substitutional alloys (similar radii), and interstitial alloys (smaller atoms in holes).	Draw particulate diagrams comparing substitutional vs. interstitial alloys and present an oral argument detailing their mechanical properties.
LT5	"Lewis Structure Speed Challenge" drawing electron dot structures for	Step-by-step Lewis structure protocol card [Valence count -> single bonds ->	Submit hand-drawn or digital Lewis diagrams incorporating resonance

	molecules with expanded octets and resonance.	octets -> formal charge optimization: FC = V - N - (B/2)].	structures and formal charge calculations for assigned species.
LT6	3D molecular modeling lab using physical ball-and-stick kits or digital molecular viewers (e.g., MolView) to inspect molecular geometries.	VSEPR geometry chart connecting electron domains, molecular geometry, bond angles, dipoles, and hybridization.	Construct a digital portfolio or present a 3D model explaining geometry, net dipole moment, and bond order for a complex molecule.

Supporting Multilingual/English Learners (*CELP standards*)

	Emerging	Expanding	Bridging
LT1	Classify substances as ionic, covalent, or metallic using a properties chart (melting point, conductivity) and word banks.	Compare properties of ionic, covalent, and metallic substances using comparative graphic organizers and sentence starters.	Predict and explain bulk substance properties based on bond type, electronegativity differences, and valence electron behavior.
LT2	Identify equilibrium bond length (well minimum) and repulsion/attraction regions on a labeled potential energy curve.	Explain how bond order and atomic radius shift the potential energy minimum depth and position using guided prompts.	Sketch and compare potential energy curves for single, double, and triple bonds, justifying shifts in bond energy and length.
LT3	Arrange positive and negative ion cards into an alternating lattice grid, matching larger/smaller sizes to ion charges.	Explain lattice energy variations using Coulomb's law sentence frames ("*Higher charge leads to stronger attraction because...*").	Construct particulate models of ionic solids and quantitatively/qualitatively justify lattice energy trends using F proportional to (q1 * q2) / r^2.
LT4	Label "electron sea" and "cation cores" on a metallic solid diagram, sorting interstitial vs. substitutional alloy pictures.	Explain malleability and conductivity of metals and alloy structures using structured paragraph frames.	Compare interstitial and substitutional alloys, explaining how lattice alterations impact density, rigidity, and conductivity.
LT5	Draw Lewis structures for simple molecules by following a step-by-step visual checklist (octet rule, valence electron counting).	Construct Lewis diagrams including resonance structures and formal charge calculations using guided templates.	Draw correct Lewis structures for complex or expanded-octet species, evaluating resonance contributors using formal charge analysis.
LT6	Match Lewis diagrams to 3D VSEPR shape names and bond angles using a visual geometry chart.	Predict molecular geometry, bond angles, and net dipole moments using VSEPR sentence frames ("*The shape is ____ because there are ____ electron domains*").	Explain complex molecular geometry, hybridization (sp, sp2, sp3), bond polarity vectors, and overall dipole moments in written detail.

Unit Overview

In this unit, students will learn how to interpret simple graphical representations of changes in potential energy as two atoms approach each other to explain optimal bond length as well as why bonds may or may not occur. Students should also practice constructing representations and models for chemical phenomena (e.g., ionic and metallic solids) and using representations to make claims or predictions. For example, students can use VSEPR theory to draw Lewis structures of molecules and predict their three-dimensional geometry and polarity. Instead of simply connecting chemical theories to phenomena occurring at the atomic level, it is important to provide explanations across scales. For example, teachers can ask students to explain the connection between electronegativity and ionization energy with the type of bond formed and the macroscopic properties of a particular substance. Students should also work with several chemical concepts (Coulomb's law, formal charge, and resonance) to evaluate the accuracy of a model in representing both the particulate-level structure and macroscopic observations. In future units, students will use the practice of constructing and understanding molecular representations to make predictions and claims about interparticle interactions, intermolecular forces, and their connections to macroscopic observations.

Lesson	Learning Target	Success Criteria	Suggested Activities
2.1 Types of Chemical Bonds	**Learning Target 1** I can explain the relationship between the type of bonding and the properties of the elements participating in the bond.	• I can classify a compound as ionic, polar covalent or nonpolar covalent, network ionic or metallic, I can describe the Trends on the periodic table electronegativity. • I can describe the qualitatively relationship between the trends and the electronic structure of the atoms, using the shell model, and Coulomb's law. • I can describe how valence electrons shared between atoms of similar electronegativity constitute a nonpolar covalent bond. For example, bonds between carbon and hydrogen are effectively nonpolar.	

		• I can describe polar covalent bond including how: i. The atom with a higher electronegativity will develop a partial negative charge relative to the other atom in the bond. ii. In single bonds,greater differences in electronegativity lead to greater bond dipoles iii. The difference between ionic and covalent bonds is not distinct but rather a continuum. • I can explain that the best way to characterize the type of bonding in the compound is to examine the properties of a compound • I understand that in a metallic solid, the valence electrons from the metal atoms are considered to be delocalized and not associated with any individual atom.	
2.2 Intramolecular Force and Potential Energy	**Learning Target 2** I can represent the relationship between potential energy and distance between atoms, based on factors that influence the interaction strength.	• I can interpret a graph of potential energy versus the distance between atoms (internuclear distance) as a useful representation for describing the interactions between atoms. Such graphs illustrate both the equilibrium bond length (the separation between atoms at which the potential energy is lowest) and the bond energy (the energy required to separate the atoms). • In a covalent bond, the bond length is influenced by both the size of the atom's core and the bond order (i.e., single, double, triple). Bonds with a higher order are shorter and have larger bond energies. • I can use Coulomb's law to understand the strength of interactions between cations and anions. i. Because the interaction strength is proportional to the charge on each ion, larger charges lead to stronger interactions ii. Because the interaction strength increases as the distance between the centers of the ions (nuclei) decreases, smaller ions lead to stronger interactions.	**Think-Pair-Share** After a review of the graph of potential energy versus internuclear distance in a hydrogen molecule, have students pair up and describe what they believe the graph would look like for various other molecules.
2.3 Structure of Ionic Solids	**Learning Target 3** I can represent an ionic solid with a particulate model that is consistent with Coulomb's law and the properties of the constituent ions	• The cations and anions in an ionic crystal are arranged in a systematic,periodic 3-D array that maximizes the attractive forces among cations and anions while minimizing the repulsive forces.	**Explore Representations** Demonstrate a model of ionic bonding. Put opaque adhesive tape on top of disk magnets to make "+" and "–" signs. Be sure to affix the tape on opposite sides for the differing charges (so that opposite ions have opposite magnetic polarity when arranged on a flat surface). Arrange the ions in an alternating array on the overhead

			projector to show the structure of an ionic crystal. Engage students in a discussion about malleability/ brittleness, and ask why distorting an ionic crystal causes shattering. This also introduces Coulombic forces in a visual and memorable way. Then have students predict and identify the bonding in binary compounds using periodic trends.
2.4 Structure of Metals and Alloys	**Learning Target 4** I can represent a metallic solid and/or alloy using a model to show essential characteristics of the structure and interactions present in the substance.	• Metallic bonding can be represented as an array of positive metal ions surrounded by delocalized valence electrons (i.e.,a"sea of electrons"). • I can describe the differences between types of alloys. Interstitial alloys form between atoms of significantly different radii,where the smaller atoms fill the interstitial space between the larger atoms (e.g., with steel in which carbon occupies the interstices in iron). • Substitutional alloys form between atoms of comparable radius, where one atom substitutes for the other in the lattice. (e.g., in certain brass alloys, other elements, usually zinc, substitute for copper.)	**Manipulatives** Have students use various sized/colored paper plates to illustrate a particular type of alloy (interstitial and/or substitutional). Then have them engage in a gallery walk around the room to listen to others explain the connection between the structure of the different alloys and the properties of each.
2.5 Lewis Diagrams & 2.6 Resonance and Formal Charge	**Learning Target 5** I can represent a molecule with a Lewis diagram.	• I can draw lewis diagrams for compounds including those with expanded octets. • I can use the concept of resonance structures to describe compounds • I can use the octet rules and formal charge as criteria for determining which of several possible valid Lewis diagrams is the best model	**Simulations** Construct various VSEPR shapes using balloons to show the three-dimensional arrangement of atoms in various bonding arrangements. Then use a PhET simulation to help students see the effects of lone pairs and bonding pairs on molecular shape. Students can work on this individually after being shown how to use the interface, or it can be projected and examined as a class. Have students work with the simulation to add/remove bonds and add/remove lone pairs to determine the most likely three-dimensional shape and bond angles in a molecule.
2.7 VSEPR and Hybridization	**Learning Target 6** Based on the relationship between Lewis diagrams, VSEPR theory, bond orders, and bond polarities: I can … i. Explain structural properties of molecules	• I can use VSEPR theory(Coulombic repulsion between electrons) as a basis for predicting the arrangement of electron pairs around a central atom. • I can use both Lewis diagrams and VSEPR theory for predicting electronic and structural properties of	**Simulations** (See 2.5 & 2.6)

	ii. Explain electron properties of molecules.	many covalently bonded molecules and polyatomic ions, including the following: i. Molecular geometry (linear, trigonal planar, tetrahedral, trigonal pyramidal, bent, trigonal bipyramidal,seesaw,T-shaped,octahedral, square pyramidal, square planar) ii. Bond angles iii. Relative bond energies based on bond order iv. Relative bond lengths (multiple bonds, effects of atomic radius) v. Presence of a dipole moment vi. Hybridization Of Valence Orbitals Of Atoms within a molecule or polyatomic ion Vii. sigma and pi bonds. The overlap is stronger in sigma than pi bonds,which is reflected sigma bonds having greater bond energy than pi bonds. The presence of a pi bond also prevents the rotation of the bond and leads to geometric isomers.	

Progress Check 2

- Multiple-choice: ~15 questions
- Free-response: 1 question
    - Long

Preparing for the AP Exam

On the AP Exam, students must be able to construct Lewis structures and make predictions or claims based on them. However, students often struggle to predict the correct molecular shape or bond angle based on VSEPR and the use of formal charge. Mistakes include: using the incorrect number of valence electrons, violating the octet rule, or confusing molecular geometry with bond angles. Teachers can provide students with multiple opportunities to practice drawing Lewis electron-dot diagrams, including resonance structures. Students should also practice predicting and describing molecular shapes, bond angles, and polarities from Lewis structures, and calculating and connecting formal charges in Lewis structures to the predicted structure of a molecule.

Unit Title:

Unit 3: Properties of Substances and Mixtures

Relevant Standards: Bold indicates priority

3.1 Intermolecular & Interparticle Forces: Students can identify and compare intermolecular forces, including dispersion, dipole-dipole, hydrogen bonding, and ion-dipole interactions, and relate them to molecular structure and particle interactions in solution.

3.2 Types of Solids & Properties: Students can classify solids as molecular, ionic, metallic, or network covalent and relate solid type and bonding to macroscopic properties.

3.3 States of Matter: Students can describe solids, liquids, and gases in terms of particle motion, spacing, and intermolecular forces.

3.4 Ideal Gases: Students can use the ideal gas law to relate pressure, volume, temperature, and moles of gas under ideal conditions.

3.5 Gases & Kinetic Molecular Theory: Students can explain gas behavior using kinetic molecular theory assumptions and relate molecular motion to measurable gas properties.

3.6 Deviations from Ideal Behavior: Students can explain how real gases deviate from ideal behavior based on particle volume and intermolecular forces, especially under high pressure and low temperature.

3.7 Solutions & Mixtures: Students can calculate and interpret solution concentration using molarity and related quantitative relationships.

3.8 Particulate Diagrams of Solutions: Students can represent solutions at the particle level to show solute-solvent interactions and relative concentrations.

3.9 Separation of Solutions and Mixtures: Students can describe and select appropriate separation techniques based on differences in physical and chemical properties of mixture components.

3.10 Solubility: Students can predict solubility based on intermolecular forces and explain factors that affect solubility of solutes in solvents.

3.11 Spectroscopy and Electromagnetic Spectrum: Students can describe the electromagnetic spectrum and relate wavelength, frequency, and energy of electromagnetic radiation.

3.12 Photons: Students can explain the particle nature of light and relate photon energy to frequency and electronic transitions.

3.13 Beer's Law: Students can use Beer's Law to relate absorbance to concentration and apply spectrophotometric data to determine solution concentration.

Essential Question(s):	**Enduring Understanding(s):**
1. How do interactions between particles influence the properties of pure substances and mixtures? 2. Why does the smell of perfume only last for a short time? 3. Why can you swim in water, but you can't walk through a wall? 4. How does the spacing and motion of particles relate to a substance's state of matter and the properties of gases? 5. How can you determine the structure and concentration of a chemical species in a mixture?	1. The nature and strength of intermolecular forces determine the physical properties of substances, including phase, boiling point, and solubility. 2. The arrangement and motion of particles in different states of matter are governed by intermolecular forces and kinetic energy. 3. The interactions between solute and solvent particles determine the formation, stability, and concentration of solutions. 4. Interactions between matter and electromagnetic radiation provide experimental evidence for atomic and molecular structure and allow for quantitative analysis of chemical systems.

Demonstration of Learning:	Pacing for Unit
• Success with Unit 3 MCQs and FRQs via AP Classroom • Quizzes (AP Classroom MCQs and FRQs) every few topics • Practice calculations with ideal gas law and combined gas law equations • Molar Mass of a Gas Lab • Particulate view of solids, liquids, gases, solutions • Making Solutions / Beer's Law Lab • Progress Check 3 from AP Classroom Unit 3 is 18–22% AP Exam Weighting See AP Exam Description	18 days of instruction 3 days of lab 3 days review / assess
Family Overview (link below)	**Integration of Technology:**
AP Chemistry FAMILY MATERIALS	• Use of LabQuests / colorimeters to make and test solutions for Beer's Law • Google Suite to graph digitally
Unit-specific Vocabulary:	**Aligned Unit Materials, Resources, and Technology (beyond core resources):**
state of matter, solid, liquid, gas, intermolecular forces, intramolecular forces, chemical bond, ionic bond, covalent bond, metallic bond, London dispersion forces, polarizability, dipole–dipole forces, hydrogen bonding, polar molecule, nonpolar molecule, electronegativity, electronegativity difference, bond polarity, molecular polarity, electron density, partial charge, molecular geometry, Lewis structure, VSEPR theory, electron domain, bonding pair, lone pair, bond angle, linear, bent, trigonal planar, trigonal pyramidal, tetrahedral, square planar, square pyramidal, octahedral, trigonal bipyramidal, hybridization, sigma bond, pi bond, single bond, double bond, triple bond, bond length, bond energy, lattice energy, Coulomb's law, melting point, boiling point, vapor pressure, volatility, surface tension, viscosity, capillary action	Colorimeter (AP suggests using a spectrophotometer, as of 8/2026 this equipment is not available for use in BPS)
Opportunities for Interdisciplinary Connections:	**Anticipated misconceptions:**
• Biology: membrane structure, protein folding, transport of substances • Earth Science: water cycle, atmospheric gases, climate systems • Physics: kinetic molecular theory and gas behavior • Environmental Science: pollution, solubility, water treatment • Medical Science: spectroscopy and diagnostic imaging	• With practice, students can identify the type of IMFs present within a sample, but may struggle to identify which explains specific observations such as boiling or melting point • When given data that contradicts typical behavior, students may struggle to find reasonable explanation as to why • Confusing intramolecular and intermolecular • Difficulty graph reading with Beer's Law • Difficulty picking appropriate equation for gas law calculations • Deviations from ideal gas: identifying which factor causes a gas to deviate from ideal behavior, but difficulty in explaining why that factor causes a deviation.
Connections to Prior Units:	**Connections to Future Units:**

• Type of bond / valence electrons dictates how a substance dissolves
• Type of bond is determined by electronegativity difference, which also dictates intermolecular forces
• Properties of photons, spectroscopy, and the electromagnetic spectrum relate to excitation of electrons (introduced in unit 1)
	• Making solutions comes up throughout the remainder of the curriculum
	  ○ Making solutions in lab
	  ○ Calculating the molarity (i.e. of an acidic or basic solution (Unit 8)
	• How a substance dissolves (i.e. ionic dissociates vs molecular compounds do not) is relevant for net ionic equations (4.2) and acids and bases (unit 8)
	• Kinetic molecular theory returns in unit 5 to explain rate of reactions

Differentiation through *Universal Design for Learning*

	Engagement	Representation	Action & Expression
LT1	Surface tension and evaporative cooling race measuring temperature drops of organic liquids on paper strips.	Structural comparison chart detailing London Dispersion Forces (polarizability/electron cloud size), Dipole-Dipole, and Hydrogen Bonding.	Write a comparative analysis or record a video explaining boiling point trends across homologous series based on IMF strength.
LT2	"Solid Classification Mystery" sorting mystery materials into ionic, metallic, covalent network, or molecular solid classes.	Visual taxonomy matrix linking solid type (e.g., Diamond vs. Ice vs. Cu vs. NaCl) to melting point, hardness, and conductivity.	Design a digital infographic or deliver an oral presentation mapping microscopic solid interactions to macroscopic material properties.
LT3	Phase change animation challenge illustrating particle motion, spacing, and intermolecular interaction breaks.	Side-by-side particulate box diagrams depicting particle arrangement, freedom of motion, and density across solid, liquid, and gas states.	Draw or animate particulate representations of a substance undergoing phase changes and defend particle density and organization.
LT4	"Gas Law Simulator" adjusting volume, temperature, and moles to observe real-time pressure responses on a digital gauge.	Formula organizer highlighting PV = nRT, Dalton's Law of Partial Pressures, and mole fraction relationships.	Solve gas stoichiometry and partial pressure problems via handwritten calculation steps, calculator logs, or video tutorials.
LT5	Maxwell-Boltzmann distribution interactive exploration observing how temperature shifts speed profiles of light vs. heavy gas molecules.	Annotated Maxwell-Boltzmann curve graphs (X-axis: molecular speed; Y-axis: number of molecules) showing temperature and molar mass shifts.	Explain the Kinetic Molecular Theory assumptions and interpret a Maxwell-Boltzmann distribution graph via a written essay or oral report.
LT6	High-pressure/low-temperature real gas simulation demonstrating deviations from ideal PV/RT = 1 baselines.	Comparative visual diagram contrasting ideal point-mass particles with real gas particles possessing finite volume and IMFs.	Write a technical memo evaluating why a specific real gas deviates from ideal behavior under extreme pressure and temperature conditions.
LT7	Solution preparation lab making precise molarity solutions and executing serial dilution procedures.	Volumetric calculation guide highlighting M = n / V and dilution formula M1V1 = M2V2 with step-by-step unit checks.	Complete solution preparation calculations and submit a recorded laboratory demonstration of accurate volumetric technique.
LT8	"Microscopic Mixer Challenge" drawing solute and solvent particles to accurately reflect molar concentration and ion-dipole orientation.	Particulate diagrams showing ion-dipole orientation (e.g., water oxygen facing Na+, hydrogen facing Cl-) and solute particle counts.	Create particulate drawings representing solutions of varying concentrations and defend the orientation of solvent molecules around ions.
LT9	Paper or thin-layer chromatography (TLC) lab separating plant pigments or dye mixtures using polar vs. nonpolar solvents.	Annotated chromatogram diagrams mapping retention factor to stationary vs. mobile phase IMF affinities.	Calculate R_f values from experimental TLC plates and write an explanation linking component travel distance to relative polarity.
LT10	"Like Dissolves Like" lab testing miscibility of polar and nonpolar solute-solvent combinations.	Energetic solubility diagram illustrating solute-solute breaking, solvent-solvent breaking, and solute-solvent forming interactions.	Write a CER justification explaining why certain vitamins (e.g., Vitamin A vs. Vitamin C) are fat-soluble or water-soluble based on IMFs.
LT11	EM spectrum matching activity linking photon wavelengths (UV/Vis, IR, Microwave) to molecular motion types.	EM spectrum chart displaying energy transitions: Microwave -> rotation, Infrared -> vibration, UV/Vis -> electronic transitions.	Construct an explanatory anchor chart or record a video mapping light frequency to specific molecular/atomic excitation modes.

LT12	Flame test or gas discharge tube line emission spectroscopy lab identifying mystery gases.	Energy level diagram showing photon absorption (arrow up) and emission (arrow down) linked to E = hν = hc / λ.	Calculate photon energy, frequency, or wavelength for an electronic transition and present a worked solution set.
LT13	Spectrophotometry / Beer-Lambert Law lab constructing a calibration curve to find the concentration of an unknown dye solution.	Beer-Lambert Law formula scaffold (A = εbc) alongside an absorbance vs. concentration calibration graph.	Construct a Beer-Lambert calibration plot using spreadsheet software and calculate unknown sample concentration with error analysis.

Supporting Multilingual/English Learners (*CELP standards*)

	Emerging	Expanding	Bridging
LT1	Identify IMF types (London dispersion, dipole-dipole, hydrogen bonding) using a flowchart and visual structural formulas.	Compare IMF strengths between pure species or mixtures using comparative writing frames (*"Species A has stronger IMFs because..."*).	Predict and justify relative IMF strengths based on polarizability, dipole moments, and hydrogen bonding capacity in detail.
LT2	Match solid types (ionic, network covalent, metallic, molecular) to visual structural models and physical property cards.	Describe relationships between solid types and properties (vapor pressure, melting point) using graphic organizers.	Explain differences in physical properties among network covalent, molecular, ionic, and metallic solids based on particulate forces.
LT3	Select correct particulate representations for solids, liquids, and gases based on particle spacing and disorder.	Describe phase changes and particle motion differences across states using structured comparison frames.	Draw and critique particulate models representing phase transitions, incorporating density anomalies and IMF disruption.
LT4	Identify variables in PV = nRT and calculate missing values using structured algebra templates and unit guides.	Solve gas law problems (PV = nRT, Dalton's Law) and explain variable relationships using proportional reasoning frames.	Derive and apply gas law relationships (P, V, T, n) in multi-step stoichiometry and partial pressure scenarios with written justifications.
LT5	Match Maxwell-Boltzmann distribution curves to temperature/mass labels using a visual guide.	Explain relationships between temperature, molar mass, and particle speed using KMT sentence starters.	Interpret Maxwell-Boltzmann distributions and particle collision dynamics to explain pressure, temperature, and effusion rate differences.
LT6	Identify high pressure and low temperature conditions as "non-ideal" on a gas behavior diagram.	Explain why real gases deviate from ideal behavior at low T or high P using sentence frames mentioning IMF and particle volume.	Analyze deviations from ideal gas behavior (Z = (P * V) / (R * T) != 1) quantitatively and qualitatively using real gas particle interactions.
LT7	Calculate molarity (M = moles / Liters) using a formula triangle and unit conversion cards.	Perform solution concentration and dilution calculations (M1 * V1 = M2 * V2) using step-by-step problem templates.	Solve complex solution stoichiometry and ion concentration calculations, writing out full conversion steps and justifications.
LT8	Draw solute particles dispersed in solvent molecules using provided ratio boxes and particle icons.	Describe solute-solvent interactions (e.g., ion-dipole) and relative concentration changes using particulate model frames.	Construct precise particulate representations showing ion orientation in solvation shells and relative stoichiometry in mixtures.
LT9	Match chromatography components (stationary/mobile phase) or distillation fractions to polarity labels.	Explain paper chromatography or distillation separation results using polar/nonpolar interaction sentence stems.	Analyze retention factors (Rf) or boiling points to evaluate mixture separation efficiency based on specific IMFs.
LT10	Classify combinations as "soluble" or "insoluble" using the "like dissolves like" rule and visual polarity cards.	Explain solubility differences in water vs. nonpolar solvents using ion-dipole and dipole-dipole interaction frames.	Justify solubility trends of organic and ionic compounds in polar/nonpolar solvents using enthalpy of solution and IMF analysis.
LT11	Match EM regions (UV/Vis, IR, Microwave) to transition types (electronic, vibrational, rotational) using a color chart.	Explain which EM radiation type causes specific molecular motions using guided matching prompts and sentence starters.	Articulate energy relationships (Delta E = h * nu) connecting photon frequencies to electronic, vibrational, and rotational transitions.
LT12	Label ground state, excited state, absorption, and emission on an atomic energy level diagram.	Calculate photon energy, frequency, or wavelength (Delta E = h * nu = (h * c) / lambda) using formula reference cards.	Relate energy level gaps to emission/absorption spectra lines, quantitatively connecting energy levels to photon properties.

LT13	Identify Beer's Law variables (A = e * b * c) and read absorbance values from a calibration curve graph.	Explain how absorbance changes with concentration or path length using direct-proportionality sentence frames.	Analyze Beer's Law data (A = e * b * c) to determine unknown concentrations and evaluate experimental errors (e.g., cuvette smudges).

Unit Overview

This unit requires students to draw upon claims made in Unit 2 about molecular geometry and polarity to support claims about intermolecular forces between molecules. Further, students will practice illustrating such claims by constructing particle representations of pure solids, liquids, gases, and solutions. This unit also requires students to build proficiency with mathematical reasoning skills, essential for success in the remainder of the course. Students should be able to explain relationships between variables in an equation (e.g., the ideal gas law) and then estimate the approximate value of one variable within an equation when the value of another variable changes. Students will practice these skills when choosing and implementing experimental procedures, making observations, and/or collecting data to address a question. Students can then determine the accuracy and precision of the data as well as manipulate it with known mathematical equations to support their claims (e.g., concentration of a substance, properties of substances in a mixture).

Lesson	Learning Target	Success Criteria	Suggested Activities
3.1 Intermolecular and Interparticle Forces	**Learning Target 1** I can explain the relationship between the chemical structures of molecules and the relative strength of their intermolecular forces when: i. The molecules are of the same chemical species. ii. The molecules are of two different chemical species.	• I can describe how London dispersion forces are a result of the Coulombic interactions between temporary, fluctuating dipoles.London Dispersion Forces are often the strongest net intermolecular force between large molecules. i. Dispersion Forces Increase With Increasing contact area between molecules and with increasing polarizability the molecules. ii. The Polarizability Of Molecule Increases with an increasing number of electrons in the molecule and size of the electron cloud. It is enhanced by the presence of pi bonding. iii. The term “London dispersion forces” should not be used interchangeably with “van der waals “ forces • I can explain how the dipole moment of a polar molecule leads to additional interactions with other chemical species. i. Dipole-induced dipole interactions are between a polar and nonpolar molecule. These forces are always attractive. The strength of these forces increases with the magnitude of the dipole of the polar molecule and with the polarizability of the nonpolar molecule. ii. Dipole dipole interactions occur between polar molecules. Iii Ion-dipole forces of attraction are present between ions and polar molecules.	**Demo with Q&A** Fill a long glass tube halfway with water and then layer ethanol over the top and fill the tube, leaving one inch at the top. Have a student mark the liquid level with a permanent marker and invert the tube (with thumb pressed firmly over the top) several times. A noticeable volume decrease occurs, and students should hypothesize why. Introduce a model showing the interparticle spacing between ethanol molecules and water molecules. The model takes into account the spacing between molecules and why volume is not a conserved quantity (unlike mass). Review hydrogen bonding as a relevant interparticle force for this demonstration.

		• Hydrogen bonding is a strong type of intermolecular interaction that exists when hydrogen atoms covalently bonded to the highly electronegative atoms (N, O, and F) are attracted to the negative end of a dipole formed by the electronegative atom (N, O, and F) in a different part of the same molecule. • I can describe hydrogen bonding as a strong type of intermolecular interaction that exists when hydrogen atoms covalently bonded to the highly electronegative atoms (N, O, and F) are attracted to the negative end of a dipole formed by the electronegative atom (N, O, and F)indifferent molecule,or different part of the same molecule.	
3.2 Properties of Solids	**Learning Target 2** I can describe the properties of solids and explain the relationship among the macroscopic properties of a substance, the particulate-level structure of the substance, and the interactions between these particles.	• I can describe the relationship between the properties of liquids and solids and the strengths and types of intermolecular forces present. Because intermolecular interactions are overcome completely when a substance vaporizes,the vapor pressure and boiling point are directly related to the strength of those interactions. Melting points also tend to correlate with interaction strength, but can be more subtle. • I can use Particulate-level representations, to communicate or understand how intermolecular interactions help to establish macroscopic properties. • I can describe ionic solids and that due to strong interactions between ions, ionic solids tend to have low vapor pressures, high melting points, and high boiling points. They tend to be brittle due to the repulsion of like charges caused when one layer slides across another layer. They conduct electricity only when the ions are mobile, as when the ionic solid is melted (i.e., in a molten state) or dissolved in water or another solvent. • I can describe covalent network solids, the atoms are covalently bonded together into a three dimensional network (e.g., diamond) or layers of two-dimensional networks(e.g.,graphite). These are only formed from nonmetals and metalloids: elemental (e.g., diamond, graphite) or binary compounds (e.g., silicon dioxide and silicon carbide). Due to the strong covalent interactions, covalent solids have high melting points.Three-dimensional network solids are also rigid and hard, because the covalent bond angles are fixed. However ,graphite is soft because adjacent layers can slide past each other relatively easily. 3.2.A.5 Molecular solids are composed of distinct, individual units of covalently-bonded molecules attracted to each other through relatively weak intermolecular forces. Molecular solids generally have a low melting point because of the relatively weak intermolecular forces present between the molecules. They do not conduct electricity because their valence electrons are tightly held within the covalent bonds and the lone pairs of each constituent molecule. Molecular solids are sometimes composed of very large molecules or polymers. • I can describe Metallic solids as good conductors of electricity and heat, due to the presence of free valence electrons. They also tend to be malleable and ductile, due to the ease with which the metal cores can rearrange their structure. In an interstitial alloy, interstitial atoms tend to make the lattice more rigid, decreasing malleability and ductility. Alloys typically retain a sea of mobile electrons and so remain conducting. • I can explain how large biomolecules (or polymers), noncovalent	

		interactions may occur between different molecules or between different regions of the same large biomolecule. The functionality and properties of such molecules depend strongly on the shape of the molecule, which is largely dictated by noncovalent interactions	
3.3 Solids, Liquids, and Gases	**Learning Target 3** I can represent the differences between solid, liquid, and gas phases using a particulate level model.	• I can explain how solids can be crystalline, where the particles are arranged in regular three-dimensional structure, or they can be amorphous, where the particles do not have a regular, orderly arrangement. In both cases, the motion of the individual particles is limited, and the particles do not undergo overall translation with respect to each other. The structure of the solid is influenced by interparticle interaction and the ability of the particles to pack together • I can explain how the constituent particles in liquids are in close contact with each other, and they are continually moving and colliding. The arrangement and movement of particles are influenced by the nature and strength of the forces (e.g., polarity, hydrogen bonding, and temperature) between the particles. • I can explain that solid and liquid phases for a particular substance typically have similar molar volume because, in both phases, the constituent particles are in close contact at all times. • I can explain that in the gas phase, the particles are in constant motion. Their frequencies of collision and the average spacing between them are dependent on temperature, pressure, and volume. Because of this constant motion,and minimal effects of forces between particles, a gas has neither a definite volume nor definite shape.	**Explore Representations** Have students create particle representations for samples of solid, liquid, and gaseous H2O. Each diagram should contain 10 molecules, and students should show how the placement and motion of the particles varies in each phase.
3.4 Ideal Gas Law	**Learning Target 4** Explain the relationship between the macroscopic properties of a sample of gas or mixture of gases using the ideal gas law. EQN: PV = nRT.	• I can describe gas mixtures such that in a sample containing a mixture of ideal gases, the pressure exerted by each component (the partial pressure) is independent of the other components. Therefore, the partial pressure of a gas within the mixture is proportional to its mole fraction (X), and the total pressure of the sample is the sum of the partial pressures.	
3.5 Kinetic Molecular Theory	**Learning Target 5** I can explain the relationship between	• I can explain the kinetic molecular theory (KMT) that relates the macroscopic properties of gases to motions of the particles in the gas. The Maxwell-Boltzmann Distribution Describes The distribution of the	

	the motion of particles and the macroscopic properties of gases with: i. The kinetic molecular theory (KMT). ii. A particulate model. iii. A graphical representation.	kinetic energies of particles at a given temperature. Also that all the particles in a sample of matter are in continuous, random motion. The average kinetic energy of a particle is related to its average velocity by the equation: EQN: KE = ½ mv2 . • The Kelvin temperature of a sample of matter is proportional to the average kinetic energy of the particles in the sample. TheMaxwell-Boltzmanndistributionprovides a graphical representation of the energies/ velocities of particles at a given temperature.	
3.6 Deviation from Ideal Gas Law	**Learning Target 6** I can explain the relationship among non-ideal behaviour of gases, interparticle forces, and/or volumes.	• The ideal gas law does not explain the actual behavior of real gases. Deviations from the ideal gas law may result from interparticle attractions among gas molecules, particularly at conditions that are close to those resulting in condensation. Deviations may also arise from particle volumes, particularly at extremely high pressures.	
3.7 Solutions and Mixtures	**Learning Target 7** I can calculate the number of solute particles, volume, or molarity of solutions	• I can describe solutions as sometimes called homogeneous mixtures, which can be solids, liquids, or gases. In a solution, the macroscopic properties do not vary throughout the sample. In a heterogeneous mixture, the macroscopic properties depend on location in the mixture. • Solution composition can be expressed in a variety of ways; molarity is the most common method used in the laboratory. EQN: M = nsolute /Lsolution	**Explore Representations** Begin by telling students that hexane does not mix with water, but ethanol does. Then have them create a particulate representation of each of the mixtures (which illustrate the interactions between the molecules that allow/disallow the solubility).
3.8 Representations of Solutions	**Learning Target 8** I can use particulate models for mixtures to : i. Represent interactions between components. ii. Represent concentrations of components.	• I can use particulate representations of solutions to communicate the structure and properties of solutions, by illustration of the relative concentrations of the components in the solution and/or drawings that show interactions among the components.	**Explore Representations** (See 3.7)
3.9 Separation of Solutions and Mixtures	**Learning Target 9** I can explain the results of a separation experiment based on intermolecular interactions.	• I can explain how the components of a liquid solution cannot be separated by filtration.They Can,however, be separated using processes that take advantage of differences in intermolecular interactions of the components. • i. Chromatography(paper,thin-layer,and column) separates chemical species by taking advantage of the differential strength of intermolecular interactions between	**Post-Lab Discussion** After investigating three different dyes using chromatography, have students determine which of the three dyes is the most polar based on macroscopic observations and an understanding of the interactions between the dyes and the solvent, or between the dyes and the paper. Then have them discuss their answers (based on evidence) and evaluate the strengths of each other's

		and among the components of the solution (the mobile phase) and with the surface components of the stationary phase. The resulting chromatogram can be used to infer the relative polarities of components in a mixture. • ii. Distillation separates chemical species by taking advantage of the differential strength of intermolecular interactions between and among the components and among the components and the effects these interactions have on the vapor pressures of the components in the mixture.	claims using both the evidence and understanding of intermolecular forces.
3.10 Solubility	**Learning Target 10** I can explain the relationship between the solubility of ionic and molecular compounds in aqueous and nonaqueous solvents, and the intermolecular interactions between particles.	• Substances with similar intermolecular interactions tend to be miscible or soluble in one another.	
3.11 Spectroscopy and the Electromagnetic Spectrum	**Learning Target 11** I can explain the relationship between a region of the electromagnetic spectrum and the types of molecular or electronic transitions associated with that region.	• I can describe the difference in absorption or emission of photons in different spectral regions is related to the different types of molecular motion or electronic transition: i. Microwave radiation is associated with transitions in molecular rotational levels. ii. Infrared radiation is associated with transitions in molecular vibrational levels. iii. Ultraviolet/visible radiation is associated with transitions in electronic energy levels.	
3.12 Properties of Photons	**Learning Target 12** I can explain the properties of an absorbed or emitted photon in relationship to an electronic transition in an atom or molecule.	• When a photon is absorbed (or emitted) by an atom or molecule, the energy of the species is increased (or decreased) by an amount equal to the energy of the photon. The wavelength of the electromagnetic wave is related to its frequency and the speed of light by the equation: EQN: $c = \lambda\nu$. • The energy of a photon is related to the frequency of the electromagnetic wave through Planck's equation: EQN: $E = \hbar\nu$.	
3.13 Beer-lambert law	**Learning Target 13** I can explain the amount of light absorbed by a solution of molecules or ions in relation to the concentration, path length, and molar absorptivity.	• I can use TheBeer-Lambert law to relate the absorption of light by a solution to three variables according to the equation: EQN: $A = \varepsilon bc$. • The molar absorptivity, ε, describes how intensely a chemical species absorbs light of a specific wavelength. The Pathlength,b, and concentration, c, are proportional to	**Predict and Confirm** Have students use a Sep-Pak C18 Cartridge (Flinn Scientific AP8917) to separate Grape Kool-Aid into its component red and blue dyes. Then have them compare the separated dyes to reference solutions of common food dyes using a spectrophotometer and measure

		the number light-absorbing particles in the lit path. In most experiments the path length and wavelength of light are held constant. In such cases,the absorbance is proportional only to the concentration of absorbing molecules or ions. The Spectrophotometer Is typically set to the wavelength of maximum absorbance (optimum wavelength) for the species being analyzed to ensure the maximum sensitivity of measurement.	the percent transmittance at 25 nm intervals across the range of 400 nm–750 nm.

Progress Check 3

- Multiple-choice: ~30 questions
- Free-response: 2 questions
    - Short
    - Short

Preparing for the AP Exam

On the AP Exam (in both the multiple-choice and the free-response section), students are required to compare the physical properties of substances and relate them to the attractive forces between particles. Students often struggle with questions that require them to determine the forces of attraction that are present between molecules. Moreover, it can be challenging for them to determine which forces are most important in explaining the differences in physical properties, such as melting points, boiling points, and vapor pressures of molecules in the solid and/or liquid state. Students also confuse the terms intramolecular and intermolecular forces. Another common mistake students make is to simplify their explanations about governing intermolecular forces in a substance by using terms such as "strong" and "weak." Teachers can ensure that students can identify an actual intermolecular force and explain its strength in relation to other forces at play.

Unit Title:

Unit 4: Chemical Reactions

Relevant Standards: Bold indicates priority

4.1 Introduction for Reactions: Students can represent chemical reactions using balanced chemical equations and identify physical states and conservation of matter in reactions.

4.2 Net Ionic Equations: Students can write complete and net ionic equations and identify spectator ions in aqueous reactions.

4.3 Representations of Reactions: Students can represent chemical reactions at the macroscopic, particulate, and symbolic levels to demonstrate conservation of matter.

4.4 Physical and Chemical Changes: Students can distinguish between physical and chemical changes based on particle rearrangement and observable evidence.

4.5 Stoichiometric Relationships: Students can use mole ratios from balanced equations to relate quantities of reactants and products.

4.6 Introduction to Titration: Students can analyze titration data to determine the concentration of an unknown solution using stoichiometric relationships.

4.7 Types of Chemical Reactions: Students can classify chemical reactions as precipitation, acid-base, or redox based on reactants, products, and observable changes.

4.8 Introduction to Acid-Base Reactions: Students can identify acid-base reactions and represent proton transfer processes using chemical equations.

4.9 Oxidation-Reduction Reactions: Students can identify redox reactions, assign oxidation states, and determine electron transfer between species.

Essential Question(s):	**Enduring Understanding(s):**
1. What makes fireworks explode? 2. In what ways can a chemical change be described and documented? 3. How can you predict that a chemical reaction will generate enough product?	1. Chemical reactions involve the rearrangement of atoms through the breaking and forming of bonds, resulting in the conservation of matter. 2. Balanced chemical equations and net ionic equations provide multiple representations of chemical reactions that describe changes at the macroscopic, particulate, and symbolic levels. 3. Stoichiometric relationships in balanced reactions allow chemists to predict the quantities of reactants and products and analyze experimental data such as titrations. 4. Chemical reactions can be classified by patterns of behavior, including acid-base, precipitation, and redox reactions, based on particle-level interactions and electron transfer.
Demonstration of Learning:	**Pacing for Unit**

• Success with unit MCQs and FRQs via AP Classroom
• Quizzes (AP Classroom MCQs and FRQs) every few topics
• Balancing chemical reaction practice
• Stoichiometry calculation practice
  ○ Limiting and excess calculations
  ○ Solution stoichiometry
• Chemical vs Physical Change Lab
• Precipitation Lab
	9 days of instruction
	2 days of lab
	2 days review / assess

• Practice with determining oxidation/ reduction numbers and writing out half reactions • Progress Check 4 from AP Classroom Unit 4 is 7-9% of AP Exam Weighting See AP Exam Description	
Family Overview (link below)	**Integration of Technology:**
AP Chemistry FAMILY MATERIALS	N/A
Unit-specific Vocabulary:	**Aligned Unit Materials, Resources, and Technology (beyond core resources):**
chemical reaction, reactant, product, chemical equation, balanced equation, stoichiometric coefficient, law of conservation of mass, combination reaction, decomposition reaction, single-replacement reaction, double-replacement reaction, combustion reaction, precipitation reaction, acid–base reaction, oxidation–reduction reaction, oxidation, reduction, oxidizing agent, reducing agent, oxidation number, redox reaction, spectator ion, total ionic equation, net ionic equation, solubility, solubility rules, aqueous solution, electrolyte, strong electrolyte, weak electrolyte, nonelectrolyte, limiting reactant, excess reactant, theoretical yield, actual yield, percent yield, mole ratio, stoichiometry, mass–mass calculation, mass–mole calculation, mole–mole calculation	N/A
Opportunities for Interdisciplinary Connections:	**Anticipated misconceptions:**

• Environmental Science: combustion, acid rain, water chemistry
• Biology: cellular respiration and metabolic reactions
• Engineering: industrial synthesis and reaction efficiency
• Mathematics: stoichiometry and proportional reasoning
• Earth Science: geochemical cycling and mineral formation
	• Not following the law of conservation of matter when balancing
	• Difficulty with stoichiometry calculations
	  ○ Comparing mass to mass when determining limiting / excess
	  ○ Not using dimensional analysis correctly when doing stoich problems
	• Difficulty with net ionic equations
	  ○ Including spectator ions
	  ○ Not including correct charge (must memorize main group charges, common transition metals, and common polyatomic ions)
	• Confusing percent yield and percent error calculations

Connections to Prior Units:	**Connections to Future Units:**
• Electrons determine charge in ionic compounds– need to know in order to write out proper net ionic equation • Type of substance (ionic vs molecular (unit 2)) determines how to write out net ionic equation • Type of substance (unit 2) determines type of reaction	• Net ionic equations show up throughout the curriculum – in unit 7 for equilibrium expressions, unit 8 for acid/ base equilibrium and reactions, unit 9 for oxidation / reduction half reactions • Oxidation reduction returns in unit 9 for electrochemistry

Differentiation through *Universal Design for Learning*

	Engagement	Representation	Action & Expression
LT1	"Chemical vs. Physical Station Lab" observing color changes, gas evolution, precipitation, temperature shifts, and phase changes.	T-chart matrix contrasting chemical changes (bond breaking/forming, new substances) with physical changes (interparticle distance shifts).	Record a video walkthrough of demonstration stations classifying each event as physical or chemical based on observational evidence.
LT2	"Net Ionic Equation Puzzles" balancing complete molecular, total ionic, and net	Step-by-step transformation guide showing how to split strong	Write balanced molecular, complete ionic, and net ionic equations for

	ionic equations by removing spectator ions.	electrolytes into ions while keeping solids, liquids, and weak acids intact.	assigned reactions using digital whiteboards or problem sets.
LT3	LEGO or atomic sphere building activity modeling conservation of atoms across chemical reactions.	Before-and-after reaction box diagrams displaying conservation of matter and correct stoichiometric atom counts.	Draw particulate representations of a chemical reaction before and after completion, correctly depicting limiting vs. excess reactants.
LT4	Thermite vs. ice melting comparison analyzing intramolecular covalent/ionic bond breaking vs. intermolecular force disruption.	Energy profile diagrams contrasting high-energy intramolecular bond changes (chemical) with lower-energy IMF changes (physical).	Write a comparative essay or record a video explaining why chemical changes generally involve greater energy changes than physical processes.
LT5	"S'mores Stoichiometry" lab deriving limiting reactants, theoretical yield, and excess reactant remaining.	BCA (Before-Change-After) table scaffold for organizing mole-based stoichiometric calculations.	Solve limiting reactant stoichiometry problems by submitting BCA tables, handwritten calculations, or video explanations.
LT6	Microscale acid-base titration lab using indicators and pH meters to determine an unknown acid concentration.	Titration apparatus schematic paired with stoichiometric equivalence calculation workflow (n_acid = n_base at equivalence point).	Write a formal laboratory report detailing titration execution, equivalence point calculation, and experimental error sources.
LT7	"Reaction Classification Challenge" sorting unlabelled chemical equations into acid-base, redox, or precipitation categories.	Diagnostic decision tree evaluating proton transfer (acid-base), electron transfer/oxidation number change (redox), or solid formation.	Classify mystery chemical reactions and defend decisions using oxidation state changes, proton transfers, or solubility rules.
LT8	Brønsted-Lowry acid-base matching game identifying conjugate acid-base pairs in solution.	Structural reaction diagram highlighting proton (H+) transfer from donor (acid) to acceptor (base) forming conjugate pairs.	Write balanced Brønsted-Lowry acid-base net ionic equations and identify conjugate pairs for given reaction prompts.
LT9	"Electrochemistry Half-Reaction Balancing Lab" balancing complex redox reactions in acidic or basic solutions.	Half-reaction balancing method chart (Balance key elements -> O with H2O -> H with H+ -> e- for charge -> equalize e-).	Balance complex acidic/basic redox equations on whiteboards or submit step-by-step half-reaction calculation sheets.

Supporting Multilingual/English Learners (*CELP standards*)

	Emerging	Expanding	Bridging
LT1	Sort real-life observation cards (color change, gas produced, melting, dissolving) into Physical vs. Chemical bins.	Describe observations indicating chemical vs. physical changes using evidence-based sentence starters.	Differentiate physical vs. chemical changes at macroscopic and microscopic levels, justifying edge cases (e.g., salt dissolving).
LT2	Balance simple chemical equations by counting atom icons on reactant and product sides.	Write balanced molecular, complete ionic, and net ionic equations using solubility rules and step-by-step guides.	Predict reaction products, write net ionic equations for complex systems, and assign spectator ions with full written justifications.
LT3	Match reactant particle diagrams to correct product particle diagrams ensuring conservation of mass.	Draw particulate models showing reactants before and products after a reaction, accounting for limiting reactants.	Construct accurate particulate diagrams representing stoichiometry, limiting reactants, physical state changes, and ion conservation.
LT4	Classify processes as bond breaking (requires energy) or bond forming (releases energy) using visual cards.	Explain macroscopically observed temperature changes during physical/chemical processes using bond-breaking/forming frames.	Analyze energy changes in physical and chemical processes by comparing the relative strengths of bonds/IMFs broken vs. formed.
LT5	Complete BCA (Before-Change-After) tables for stoichiometry using simple whole-number particle counts.	Solve stoichiometry, limiting reactant, and percent yield problems using structured BCA tables and calculation steps.	Execute complex limiting reactant, theoretical yield, and excess reactant stoichiometry problems with complete written work.
LT6	Identify equivalence point volume on a titration curve graph and label burette/flask equipment.	Calculate analyte concentration at the equivalence point using titration stoichiometry templates (MA * VA = MB * VB for 1:1).	Design a titration procedure, analyze experimental titration data, and calculate analyte concentrations for non-1:1 stoichiometry.

LT7	Sort chemical reaction equations into Acid-Base, Redox, or Precipitation categories using a visual key.	Classify reaction types by identifying proton transfer, electron transfer, or precipitate formation using sentence frames.	Categorize complex reactions and justify classifications by tracking oxidation numbers, H+ transfer, or precipitate solubility.
LT8	Identify Bronsted-Lowry acids (H+ donor) and bases (H+ acceptor) in simple equations using color coding.	Write acid-base neutralization equations and identify conjugate acid-base pairs using guided templates.	Predict products of strong/weak acid-base reactions and write net ionic equations for various neutralization combinations.
LT9	Assign oxidation numbers to elements in simple binary compounds using oxidation rule reference cards.	Balance simple redox reactions by splitting them into oxidation and reduction half-reactions using guided steps.	Balance complex redox reactions in acidic or basic solutions using the half-reaction method, tracking electron conservation.

Unit Overview

In Unit 4, students will describe and construct equations of chemical systems and learn to balance those equations. Students should be able to identify and effectively represent types of reactions (e.g., acid-base, redox, precipitation) and then use that knowledge to make hypotheses or predictions about the outcome of a reaction. Additionally, students should be able to support their claims about the identity and amount of product yield through evidence gained with both experimentation and the principles of stoichiometry. Further, students should be able to determine the output of a reaction when the number of moles of reactants change or are in limited/excess supply. This practice of effectively representing balanced chemical equations and using stoichiometry to calculate outcomes of such reactions is critical to student success in the remainder of the course.

Lesson	Learning Target	Success Criteria	Suggested Activities
4.1 Introduction for Reactions	**Learning Target 1** I can identify evidence of chemical and physical changes in matter.	• I can define a physical change as occurring when a substance undergoes a change in properties but not a change in composition. Changes in the phase of a substance (solid, liquid, gas) or formation/ separation of mixtures of substances are common physical changes. • I can define a chemical change as occurring when substances are transformed into new substances, typically with different compositions.Production Of heat or light, formation of a gas, formation of a precipitate, and/or color change provide possible evidence that a chemical change has occurred.	
4.2 Net Ionic Equations	**Learning Target 2** I can represent changes in matter with a balanced chemical or net ionic equation: i. For physical changes. ii. For given information about the identity of the reactants and/or product iii. For ions in a given chemical reaction.	• I can represent physical and chemical processes symbolically by balanced equations. These processes are the result of a rearrangement of atoms into new combinations; thus, any representation of a chemical change must contain equal numbers of atoms of every element before and after the change occurred. Equations thus demonstrate that mass and charge are conserved in chemical reactions. • Balanced molecular, complete ionic, and net ionic equations are different symbolic forms used to represent a chemical reaction. The form used to represent the reaction depends on the context in which it is to be used.	**Explore Representations** Have students work through an online simulation of particulate-level representations of various single-displacement reactions. Then have them translate these particle level views into net ionic equations
4.3 Representations of	**Learning Target 3** I can represent a given chemical reaction or	• I can balance chemical equations in their various forms and translate them into	**Explore Representations** (See 4.2)

Reactions	physical process with a consistent particulate model.	symbolic particulate representations.	
4.4 Physical and Chemical Changes	**Learning Target 4** I can explain the relationship between macroscopic characteristics and bond interactions for: i. Chemical processes ii. Physical processes.	• I can describe the processes that involve the breaking and/or formation of chemical bonds as chemical processes. Processes that involve only changes in intermolecular interactions, such as phase changes, are typically classified as physical processes. Sometimes physical processes involve the breaking of chemical bonds. For example, plausible arguments could be made for the dissolution of a salt in water, as either a physical or chemical process, involves breaking of ionic bonds, and the formation of ion-dipole interactions between ions and solvent.	
4.5 Stoichiometry	**Learning Target 5** I can explain changes in the amounts of reactants and products based on the balanced reaction equation for a chemical process.	• I can explain that because atoms must be conserved during a chemical process, it is possible to calculate product amounts by using known reactant amounts, or to calculate reactant amounts given known product amounts. Coefficients Of Balanced Chemical equations contain information regarding the proportionality of the amounts of substances involved in the reaction. These values can be used in chemical calculations involving the mole concept. Stoichiometric calculations can be combined with the ideal gas law and calculations involving molarity to quantitatively study gases and solutions.	**Simulations** Have students view a simulated reaction pertaining to a limiting reagent problem. Each iteration of the simulation provides students with different unknown concentrations of the reactants from which students calculate the amount of product that is dissolved. Then have them check their answers upon completion of the simulation.
4.6 Introduction to Titration	**Learning Target 6** I can perform titrations and identify the equivalence point in a titration based on the amounts of the titrant and analyte, assuming the titration reaction goes to completion.	• I can use the method of Titrations to determine the amount of an analyte in solution. The titrant has a known concentration of a species that reacts specifically and quantitatively with the analyte. The equivalence point of the titration occurs when the analyte is totally consumed by the reacting species in the titrant. The equivalence point is often indicated by a change in a property (such as color) that occurs when the equivalence point is reached. This observable event is called the endpoint of the titration.	**Think-Pair-Share** Ask students to connect four different particulate representations with a strong acid-strong base titration curve between HCl + NaOH. The representations depict the acid before base has been added, the half equivalence point of the titration, the equivalence point of the titration, and some point beyond the equivalence point (excess base). Have students defend their choices with a partner.
4.7 Types of	**Learning Target 7**	• I can describe Acid-base reactions as involving transfer	**Critique Reasoning** After a review of different types of chemical reactions

Chemical Reactions	I can identify a reaction as acid base, oxidation-reduction, or precipitation.	of one or more protons (H+ ions) between chemical species. And Oxidation-reduction(redox)reactions as involving the transfer of one or more electrons between chemical species, as indicated by changes in oxidation numbers of the involved species. Also,combustion is an important subclass of oxidation-reduction reactions,which species reacts with oxygen gas. In the case of hydrocarbons, carbon dioxide and water are products of complete combustion. In a redox reaction, electrons are transferred from species that are oxidized to the species that is reduced. • I can assign Oxidation numbers to each of the atoms in the reactants and products; this is often an effective way to identify the oxidized and reduced species in a redox reaction. • I can describe how precipitation reactions frequently involve mixing ions in aqueous solution to produce an insoluble or sparingly soluble ionic compound. All sodium, potassium, ammonium, and nitrate salts are soluble in water	(acid-base, redox, precipitation), give students a series of 10 reactions (both the equation and a short demo of the reaction taking place). Have them identify what type of reaction is taking place and justify that claim with evidence. Then have them pair up and evaluate the strength of each other's claims.
4.8 Introduction to Acid-Base Reactions	**Learning Target 8** I can describe and write acid base reactions	• I can identify species as Brønsted Lowry acids, bases, and/or conjugate acid-base pairs, based on proton-transfer involving those species. • I can describe amphoteric species. • When an acid or base ionizes in water, I can identify the conjugate acid-base pairs and compare their relative strengths.	
4.9 Oxidation-Reduction (Redox) Reactions	**Learning Target 9** I can represent a balanced redox reaction equation using half-reactions	• I can construct balanced chemical equations for redox reactions from half-reactions	**Simulations** After viewing a simulation on metal/metal ion reactions, provide students with several 1 molar solutions and a piece of aluminum and ask them to select a solution that would react to coat the Al. Students who select incorrect solutions should go back and revisit the simulation.
Progress Check 4 • Multiple-choice: ~20 questions • Free-response: 1 question			

- Long

Preparing for the AP Exam
On the AP Exam, students must be able to demonstrate proficiency in writing and balancing chemical equations (molecular, complete, net ionic) and calculating quantities in multiple contexts using more than just 1:1 stoichiometric ratios. Students often struggle with questions that require them to justify their identification of a particular type of reaction using an equation. They also encounter difficulty with determining the limiting reactant using stoichiometry. For example, with stoichiometric calculations, students often make the mistake of comparing mass to mass instead of mole to mole when determining the limiting reactant. Teachers can ensure that students practice writing balanced equations (for net ionic and molecular) and that they develop a strong understanding of the mole concept and gain proficiency with dimensional analysis. This will help them correctly calculate required quantities using stoichiometric ratios.

Unit Title:

Unit 5: Kinetics

Relevant Standards: Bold indicates priority

5.1 Reaction Rates: Students can describe reaction rate in terms of changes in concentration over time and interpret graphical representations of rate data.

5.2 Introduction to Rate Law: Students can determine the rate law from experimental data and relate reaction rate to reactant concentrations.

5.3 Concentration Changes Over Time: Students can use integrated rate laws to determine concentration, time, or rate constants for zero-, first-, and second-order reactions.

5.4 Elementary Reactions: Students can identify elementary steps in a reaction mechanism and relate molecularity to rate law expressions.

5.5 Collision Model: Students can explain how effective collisions, orientation, and activation energy determine whether a reaction occurs.

5.6 Reaction Energy Profile: Students can interpret potential energy diagrams to identify activation energy, reaction intermediates, and catalysts.

5.7 Introduction to Reaction Mechanisms: Students can describe how reaction mechanisms consist of a sequence of elementary steps that lead to an overall reaction.

5.8 Reaction Mechanisms and Rate Law: Students can determine rate laws from proposed reaction mechanisms and identify rate-determining steps.

5.9 Pre-Equilibrium Approximation: Students can apply the pre-equilibrium approximation to derive rate laws for multi-step reactions involving fast equilibria.

5.10 Multistep Reaction Energy Profiles: Students can interpret complex energy diagrams for multi-step reactions, including intermediates and multiple activation energies.

5.11 Catalysts: Students can explain how catalysts increase reaction rate by providing an alternative reaction pathway with lower activation energy without being consumed.

Essential Question(s):	**Enduring Understanding(s):**
1. * Why are some reactions faster than other reactions? 2. * Why are some medications taken every 8 hours and others once a day? 3. * Why is food stored in a refrigerator, but bread dough is kept in a warm place to rise? 4. * How can the speed of a reaction be controlled by understanding the collisions that occur on the particle level?	1. Reaction rates are determined by the frequency and effectiveness of particle collisions, which depend on concentration, temperature, and molecular orientation. 2. The rate law describes the relationship between reactant concentrations and reaction rate and must be determined experimentally, not from the balanced equation. 3. Reaction mechanisms consist of a series of elementary steps, and the slowest step (rate-determining step) controls the overall reaction rate. 4. Energy changes during reactions, including activation energy barriers, govern whether collisions result in successful product formation. 5. Catalysts increase reaction rates by providing an alternative pathway with lower activation energy without being consumed in the reaction.
Demonstration of Learning:	**Pacing for Unit**
• Success with unit MCQs and FRQs via AP Classroom • Quizzes (AP Classroom MCQs and FRQs) every few topics	10 instructional days 3 days of lab 2 days review / assess

• Practice identify reaction order based on data, graphs, equations, elementary steps, energy profiles • Practice calculating rate constant k using data, graphs, equations • Practice drawing energy profiles for single and multistep reaction mechanism • Progress Check 5 from AP Classroom Unit 5 is 7-9% of AP Exam Weighting See AP Exam Description	
Family Overview (link below)	**Integration of Technology:**
AP Chemistry FAMILY MATERIALS	N/A
Unit-specific Vocabulary:	**Aligned Unit Materials, Resources, and Technology (beyond core resources):**
reaction rate, rate of reaction, average rate, instantaneous rate, rate law, rate constant, reaction order, overall reaction order, zero-order reaction, first-order reaction, second-order reaction, integrated rate law, half-life, collision theory, activation energy, activated complex, transition state, energy diagram, reaction mechanism, elementary step, rate-determining step, intermediate, catalyst, homogeneous catalyst, heterogeneous catalyst, enzyme, temperature, concentration, surface area, reaction pathway, Arrhenius equation, frequency factor	N/A
Opportunities for Interdisciplinary Connections:	**Anticipated misconceptions:**
• Biology: enzyme activity and metabolic reaction rates • Medicine: drug dosage timing and reaction mechanisms • Environmental Science: decomposition rates and atmospheric reactions • Physics: collision theory and energy transfer • Engineering: catalysts in industrial manufacturing and automotive systems	• Difficulty with graph reading ○ Not noticing differences in y-axis labels for 0th, 1st, and 2nd order graphs • Difficulty determining units for k depending on the order of reaction • Assuming that the stoichiometric coefficients of the balanced chemical reaction determines order of the chemical reaction • Including products in rate expression • Difficulty determining k for multistep reaction mechanisms (especially when first step is fast and at equilibrium)
Connections to Prior Units:	**Connections to Future Units:**
• Kinetic molecular theory was introduced in unit 3 but also helps explain collision theory and activation energy • Balanced equations (unit 4) are needed to determine the order of elementary steps • Concentration (unit 3) is needed to perform kinetic calculations	• Energy profiles are seen again in unit 6 to determine if a reaction is endothermic or exothermic and in unit 9 • Rate constant k must be contrasted with equilibrium constant K in units 7, 8, 9 as they are different concepts.

Differentiation through *Universal Design for Learning*

	Engagement	Representation	Action & Expression
LT1	"Alka-Seltzer Reaction Rate Lab" measuring gas evolution speed across varying temperatures, particle sizes, and concentrations.	Graphical overlay showing reaction rate curves (Concentration vs. Time) steepening with temperature, surface area, or catalyst addition.	Design an experiment testing a kinetic parameter and write a lab report summarizing rate dependencies.
LT2	"Differential Rate Law Speed Challenge" deducing reaction orders (0, 1, 2) from initial rate method data tables.	Method of Initial Rates formula scaffold [Rate2 / Rate1 = ([A]2 / [A]1)^m] with rate constant k unit decoder.	Solve initial rate problems to determine rate laws and calculate k with correct units via handwritten or video solutions.

LT3	Integrated rate law graphing lab using Excel/Google Sheets to plot [A], ln[A], and 1/[A] vs. time to find linearity.	Linear graph comparison chart (0th order: [A] vs. t; 1st order: ln[A] vs. t; 2nd order: 1/[A] vs. t) with half-life formulas.	Determine reaction order from time-series concentration data by submitting linearized plots and calculating rate constant k.
LT4	Molecular collision simulation observing unimolecular vs. bimolecular collisions forming products.	Conversion chart translating elementary step stoichiometry (e.g., A + B -> Products) directly into rate law [Rate = k[A][B]].	Write rate laws for elementary reaction steps and justify why molecularity dictates order for elementary steps but not overall reactions.
	Interactive Collision Theory simulation adjusting collision speed and orientation angle to observe successful reaction percentage.	Visual collision diagrams displaying effective collisions (correct orientation + E ≥ E_a) vs. ineffective collisions (incorrect orientation or low E).	Explain Collision Theory principles and defend why increasing temperature increases effective collision percentage using a video or written report.
	Potential energy profile sketching challenge drawing activation energy barriers (E_a) and enthalpy changes (ΔH).	Annotated potential energy profile diagram labeling reactants, transition state/activated complex, products, E_a (forward/reverse), and ΔH.	Draw and label potential energy profile diagrams for endothermic and exothermic elementary reactions on whiteboards or digital tools.
	"Mechanism Detective" tracking species produced and consumed across multistep elementary mechanisms.	Color-coded mechanism table distinguishing Intermediates (produced then consumed) from Catalysts (consumed then regenerated).	Identify intermediates and catalysts in a multistep mechanism and write the overall balanced chemical equation.
	Multistep mechanism puzzle deriving the overall rate law directly from a slow first elementary step.	Flowchart showing that when Step 1 is slow, Overall Rate Law = Rate Law of Step 1 (Slow Step = Rate-Determining Step).	Derive overall rate laws for mechanisms with a slow first step and explain why step 1 governs the overall rate.
	Fast-equilibrium mechanism problem set substituting intermediate terms using reversible first-step equilibrium expressions.	Derivation scaffold showing intermediate substitution [k_f[A][B] = k_r[Intermediate]] into the slow step rate law.	Derive overall rate laws for mechanisms with a fast reversible first step using written algebraic derivations or screencast walkthroughs.
	Multistep energy profile drawing challenge modeling multi-peak reaction landscapes corresponding to mechanism steps.	Multi-peak potential energy diagram highlighting intermediate valleys, activation energy peaks for each step, and the rate-limiting peak.	Sketch a multi-peak reaction profile for a two-step mechanism, identifying the rate-determining step based on peak height.
LT5	Catalyzed reaction demonstration (e.g., decomposition of H2O2 with MnO2 or yeast) observing reaction speedup and catalyst recovery.	Side-by-side reaction energy profile showing uncatalyzed (high E_a) vs. catalyzed (lower E_a alternative pathway) curves.	Write a CER justification or record a video explaining how a catalyst accelerates a reaction without being consumed or altering ΔH.

Supporting Multilingual/English Learners (*CELP standards*)

	Emerging	Expanding	Bridging
LT1	Identify factors that speed up reactions (temperature, concentration, surface area, catalyst) using visual icon cards.	Explain how changing parameters (concentration, temperature, surface area) affects rate using cause-and-effect sentence frames.	Analyze rate data under varying experimental parameters, explaining rate changes using collision theory and kinetic energy distributions.
LT2	Identify reaction order (0th, 1st, 2nd) from simple rate law expressions (Rate = k[A]^n).	Write rate law expressions and determine units of k using structured problem-solving frames.	Derive rate law expressions, calculate rate constant k with correct units, and evaluate reaction orders from experimental data.
LT3	Match linear integrated rate law graphs ([A], ln[A], 1/[A] vs. time) to 0th, 1st, and 2nd order labels.	Determine reaction order from concentration vs. time data or graphs using guided decision templates.	Determine reaction orders, rate constants, and half-lives using graphical analysis, integrated rate laws, and initial rate data.
LT4	Write rate laws for simple unimolecular or bimolecular elementary steps (A -> B => Rate = k[A]).	Determine molecularity and write rate law expressions for elementary steps using reaction stoichiometry prompts.	Formulate rate laws for elementary steps and explain why molecularity directly dictates reaction order for elementary processes.
LT5	Circle "effective collisions" in diagrams showing correct vs. incorrect particle orientation and minimum energy.	Explain collision theory requirements (frequency, energy, orientation) using structured writing frames.	Evaluate collision dynamics and explain how temperature and orientation factors quantitatively/qualitatively affect reaction rates.

LT6	Label reactants, products, activation energy (Ea), and Delta H on a reaction coordinate diagram.	Sketch exothermic and endothermic potential energy diagrams and identify Ea and Delta H values using guided prompts.	Construct and interpret potential energy profiles, calculating Ea and Delta H for forward and reverse elementary reactions.
LT7	Identify catalysts (consumed first, produced later) and intermediates (produced first, consumed later) using color coding in a mechanism.	Categorize species in a multi-step mechanism as reactants, products, intermediates, or catalysts using structured tables.	Analyze multi-step reaction mechanisms to identify all chemical species and write the overall balanced reaction equation.
LT8	Write the overall rate law directly from the first step of a mechanism using a visual slow-step rule card.	Explain why the rate-determining step dictates the overall rate law using guided paragraph starters.	Derive the overall rate law for a mechanism with a slow initial step, justifying why subsequent steps do not affect the rate law.
LT9	Identify the slow step in a 2-step mechanism and circle the intermediate species to be substituted.	Express overall rate laws for mechanisms with fast equilibrium pre-steps using step-by-step substitution guides.	Derive overall rate laws for complex mechanisms with fast reversible initial steps using the steady-state or pre-equilibrium approximation.
LT10	Count the number of peaks (steps) and valleys (intermediates) on a multi-step potential energy diagram.	Draw multi-step energy profile diagrams identifying rate-limiting steps (Ea peak height) using guided prompts.	Construct multi-step reaction energy profiles, accurately representing relative Ea heights, intermediates, transition states, and overall Delta H.
LT11	Identify catalyzed vs. uncatalyzed curves on a reaction coordinate diagram (catalyzed peak is lower).	Explain how catalysts lower Ea and increase effective collisions using comparative sentence frames.	Analyze catalyzed vs. uncatalyzed energy profiles and collision models, explaining mechanism changes and activation energy reduction.

Unit Overview

In prior units, students developed their ability to describe symbolic and quantitative information from representations (e.g., Lewis structures, chemical reactions) that illustrate both the particulate and macroscopic level of a chemical phenomenon. In Unit 5, students will build on these explanations and representations by constructing and describing rate laws consistent with experimental evidence. To that end, students will collect data by spectrophotometry and choose an appropriate mathematical routine to determine how concentration varies with time during the course of a reaction. In addition, students will examine proposed reaction mechanisms to determine if there is a match between observed experimental data and constructed rate law expressions. Students will learn to identify any intermediates or catalysts that are included in the reaction mechanism, as well as the rate-determining step ,and be able to justify their claims. To do so, students must learn to construct and analyze energy profiles for chemical reactions and identify how such profiles may change with the addition of a catalyst.

Lesson	Learning Target	Success Criteria	Suggested Activities
5.1 Reaction Rates	**Learning Target 1** I can explain the relationship between the rate of a chemical reaction and experimental parameters.	• I can use experimental methods to monitor the amounts of reactants and/or products of a reaction over time and determine the rate of the reaction. • I can express the rate of a reaction using a rate law that shows how it depends on the concentration of each reactant raised to a power. • I can determine the order of a reaction with respect to each reactant and use this to find the overall reaction order as the sum of the individual orders. • I can describe the rate constant and explain how its value depends on temperature	**Post-Lab Discussion** As an introduction to kinetics, have students form small groups to design an experiment to establish a relationship between the rate and a specific reaction parameter of Alka-Seltzer tablets in water. Have them select varying temperature, concentration, mass, or surface area and decide which data to collect. Groups use whiteboards to present their data and major findings to the rest of the class.

		and how its units reflect the overall reaction order. ● I can use initial rate data to determine the rate law and reaction orders for a chemical reaction.	
5.2 Introduction to Rate Law	**Learning Target 2** I can represent experimental data with a consistent rate law expression	● I can use experimental data to determine a consistent rate law expression that describes how reactant or product concentrations change over time. ● I can explain how reaction rates are determined by monitoring changes in reactant or product concentrations over time. ● I can write a rate law that expresses reaction rate as proportional to the concentration of each reactant raised to a power. ● I can determine the order of a reaction with respect to each reactant and explain how the sum of these orders gives the overall reaction order. ● I can describe the rate constant, including how it depends on temperature and how its units are determined by the overall reaction order. ● I can use the method of initial rates to determine the order of a reaction with respect to each reactant.	**Post-Lab Discussion** Using a spectrophotometer, have students measure the absorbance of a solution of green food coloring after bleach has been added. Have them use Excel to prepare different graphs of the data, such as absorbance vs. time, and 1/(absorbance) vs. time. Students should use a linear regression analysis to determine the most linear fit, the order of the reaction, and the effect on the value of k when the concentration of bleach is increased. Have student groups share and compare their results.
5.3 Concentration Changes Over Time	**Learning Target 3** I can identify the rate law expression of a chemical reaction using data that show how the concentrations of reaction species change over time.	● I can determine the rate law expression of a chemical reaction using data that show how the concentrations of reactants change over time. ● I can infer the order of a reaction by analyzing a graph of reactant concentration versus time. ● I can determine if a reaction is first order by recognizing that a plot of ln(concentration) versus time is linear. ● I can determine if a reaction is second order by recognizing that a plot of 1/concentration versus time is linear. ● I can use integrated rate law equations and the slopes of linearized graphs to determine the rate constant for zeroth-, first-, and second-order	**Critique Reasoning** Using a balance and a stopwatch, have students determine the rate order of a burning birthday candle by preparing graphs in Excel, and use a linear regression analysis to determine the most linear fit and the value of the rate constant, k. Have students justify why the rate of mass disappearance of the candle does not change as the candle burns down. Then have them compare their results with other groups to see if their results are consistent.

		reactions. • I can explain that half-life is a key feature of first-order reactions because it remains constant regardless of concentration. • I can use the relationship t{1/2} = 0.693/k to calculate half-life or the rate constant for a first-order reaction. • I can describe how radioactive decay is an example of first-order kinetics.	
5.4 Elementary Reactions	**Learning Target 4** I can represent an elementary reaction as a rate law expression using the stoichiometry of the reacting particles.	• I can infer the rate law of an elementary reaction directly from its balanced equation and collision stoichiometry. • I can explain that the molecularity of an elementary step determines its rate law expression. • I can describe why elementary reactions involving the simultaneous collision of three or more particles are rare.	
5.5 Collision Model	**Learning Target 5** I can explain that the rate of an elementary reaction depends on the frequency of particle collisions, the energy of those collisions, and the orientation of the reacting particles.	• I can describe how successful reactions require collisions with sufficient energy to overcome activation energy and the correct orientation for bonds to break and form. • I can explain why only a small fraction of collisions result in a reaction, even when particles are colliding frequently. • I can use the Maxwell-Boltzmann distribution to describe the range of particle energies in a system. • I can use the Maxwell-Boltzmann distribution to explain how temperature affects the fraction of particles with enough energy to react.	
5.6 Reaction Energy Profile	**Learning Target 6** I can represent the activation energy and overall energy change of an elementary reaction using a reaction energy profile diagram.	• I can explain that elementary reactions involve the breaking of bonds in reactants and the formation of new bonds in products. • I can describe the reaction coordinate as the pathway that represents the progression of reactants through the transition state to products. • I can identify activation energy as the energy difference between the reactants and the transition state on a reaction energy profile. • I can explain how temperature affects reaction rate by changing the fraction of collisions that have enough energy to reach the transition state. • I can describe how the Arrhenius equation relates temperature and activation energy to the rate of an elementary reaction.	
5.7 Introduction to Reaction Mechanisms	**Learning Target 7** I can identify the components of a reaction mechanism, including reactants, products, intermediates, and catalysts.	• I can describe a reaction mechanism as a series of elementary steps that occur in sequence. • I can explain that the sum of all elementary steps in a mechanism must match the overall balanced chemical equation. • I can define a reaction intermediate as a species that is produced in one step and consumed in a later step, so it does not appear in the overall reaction. • I can explain how the	**Critique Reasoning** Working in small groups, have students evaluate the appropriateness of reaction mechanisms for a given reaction for which the rate law is established. Have groups share their conclusions with the rest of the class and then discuss why certain choices must be eliminated and why there might be more than one possible mechanism that is valid. Have classmates provide feedback to the groups on the validity of their conclusions.

		experimental detection of intermediates can provide evidence for or against a proposed reaction mechanism.	
5.8 Reaction Mechanism and Rate Law	**Learning Target 8** I can identify the rate law for a reaction from a mechanism in which the first step is rate limiting.	• I can explain that when each elementary step is irreversible or when the first step is slow, the rate law is determined by that slow (rate-limiting) step. • I can determine the rate law of a reaction by using the molecularity of the rate-determining step.	**Critique Reasoning** (see 5.7)
5.9 Pre-Equilibrium Approximation	**Learning Target 9** I can identify the rate law for a reaction from a mechanism in which the first step is not rate limiting.	• I can explain that when the first elementary step is not rate limiting, additional assumptions or approximations are needed to determine the rate law. • I can apply approaches such as the pre-equilibrium approximation to derive a rate law expression from a multi-step mechanism.	**Manipulatives** Give students a blank multistep reaction energy profile with a series of labels on the side. Have them work with a partner to correctly place the labels next to the blanks indicated on the profile and then share/evaluate their diagrams with another pair of students.
5.10 Multistep Reaction Energy Profile	**Learning Target 10** I can represent the activation energy and overall energy change in a multistep reaction using a reaction energy profile diagram.	• I can explain how each elementary step in a reaction mechanism contributes to the overall energy profile. • I can construct an energy profile for a multistep reaction using knowledge of the energetics of each step in the mechanism. • I can identify multiple transition states and intermediates on a multistep reaction energy diagram.	
5.11 Catalysis	**Learning Target 11** I can explain how a catalyst increases the rate of a reaction by increasing the number of effective collisions and/or providing an alternative reaction pathway with lower activation energy.	• I can describe how a catalyst participates in a reaction mechanism by being consumed in one step and regenerated in a later step, resulting in no net change in catalyst concentration. • I can explain how catalysts can form temporary bonds with reactants to improve orientation or lower activation energy, often creating new intermediates (as in enzyme catalysis). • I can describe how acid–base catalysis involves proton transfer steps that create new intermediates and modify the reaction mechanism. • I can explain how surface catalysis involves reactants binding to a surface, forming intermediates and introducing new elementary steps in the mechanism.	

Progress Check 5

- Multiple-choice: ~25 questions
- Free-response: 2 questions
    - Short
    - Long

Preparing for the AP Exam

On the AP Exam, students must be able to navigate between experimental data (tabular or graphed), a given or constructed rate law, and a proposed mechanism. Students generally struggle with reading a graph of reactant concentration versus time and drawing appropriate conclusions (i.e., order and rate constant) from the graphed data. Specifically, students confuse the units of the graphs with the units represented in the chemical equation. Teachers can ensure that students have multiple opportunities to graph concentration versus time or concentration versus rate data (using appropriate increments and units for the axes). Once students learn how to graph this data, teachers can help them analyze the graphs to determine the order of a reaction.

Unit Title:

Unit 6: Thermochemistry

Relevant Standards: Bold indicates priority

6.1 Endothermic and Exothermic Processes: Students can distinguish between endothermic and exothermic processes based on energy flow between system and surroundings.

6.2 Energy Diagrams: Students can interpret potential energy diagrams to identify enthalpy change and activation energy for reactions.

6.3 Heat Transfer and Calorimetry: Students can use calorimetry data to calculate heat absorbed or released during chemical and physical processes.

6.4 Heat Capacity and Specific Heat: Students can relate heat transfer to temperature change using specific heat capacity and mass.

6.5 Enthalpy of Phase Changes: Students can calculate energy changes associated with phase transitions using molar enthalpies of fusion, vaporization, and other phase changes, and relate these energy changes to particle interactions and changes in state.

6.6 Introduction to Enthalpy of Reaction: Students can calculate enthalpy changes using experimental data, bond energies, or Hess's Law.

6.7 Bond Enthalpies: Students can estimate enthalpy changes of reactions using bond dissociation energies.

6.8 Enthalpies of Formation: Students can calculate standard enthalpy changes using standard enthalpies of formation.

6.9 Hess's Law: Students can determine enthalpy changes for chemical and physical processes by applying Hess's Law to combine, reverse, and scale multi-step reactions to obtain an overall reaction enthalpy.

Essential Question(s):	**Enduring Understanding(s):**
1. Why is energy released when liquid water becomes an ice cube? 2. Why does your skin feel cold when water evaporates off of it? 3. How does a thermal energy transfer affect temperature, states of matter, and chemical bonds? 4. How can energy changes be tracked and measured when energy can't be seen? 5. Why do combustion reactions that form carbon dioxide release energy?	1. Energy is transferred between a system and its surroundings through heat and work, and these transfers can change the internal energy of a system. 2. Enthalpy is a state function that represents heat transfer at constant pressure, and enthalpy changes can be used to describe endothermic and exothermic processes. 3. Calorimetry allows experimental determination of heat transfer using temperature changes, heat capacity, and specific heat relationships. 4. Energy changes in chemical reactions can be calculated using Hess's Law, standard enthalpies of formation, or average bond enthalpies. 5. Phase changes and chemical processes involve energy changes associated with breaking and forming intermolecular or intramolecular interactions.
Demonstration of Learning:	**Pacing for Unit**
• Success with unit MCQs and FRQs via AP Classroom • Quizzes (AP Classroom MCQs and FRQs) every few topics • Practice with the 4 ways to calculate the enthalpy of a reaction • Practice calculating the energy involved in heating / cooling a substance ($q = mc\Delta T$) • Practice calculating energy required to change phase	9 instructional days 2 days lab 2 days review / assess

• Calorimetry/ Specific Heat Lab • Combustion of a Cheeto Lab • Practice drawing energy profiles • Progress Check 6 from AP Classroom Unit 6 is 7-9% of AP Exam Weighting See AP Exam Description	
Family Overview (link below)	**Integration of Technology:**
AP Chemistry FAMILY MATERIALS	N/A
Unit-specific Vocabulary:	**Aligned Unit Materials, Resources, and Technology (beyond core resources):**
Energy, system, surroundings, boundary, thermal energy, kinetic energy, potential energy, chemical potential energy, heat, work, temperature, internal energy, enthalpy, enthalpy change, endothermic, exothermic, calorimetry, calorimeter, coffee-cup calorimeter, bomb calorimeter, heat capacity, specific heat capacity, molar heat capacity, $q = mc\Delta T$, standard state, standard enthalpy change, standard enthalpy of formation, standard enthalpy of combustion, Hess's law, bond enthalpy, bond dissociation energy, state function, phase change, fusion, vaporization, sublimation, condensation, deposition, heating curve, cooling curve, extensive property, intensive property, first law of thermodynamics, energy transfer, reaction enthalpy, thermochemical equation, average bond enthalpy	• Digital thermometers • Bunsen burners • Calorimetry set up (double cup calorimeter)
Opportunities for Interdisciplinary Connections:	**Anticipated misconceptions:**
• Physics: conservation of energy and thermodynamics • Earth Science: phase changes, climate systems, geothermal processes • Biology: metabolism and energy transfer in living organisms • Engineering: energy efficiency, fuels, calorimetry, heat transfer systems • Environmental Science: combustion and energy resources	• Difficulty determining system vs surroundings and their change in temperature when considering an endo or exothermic reaction • Not considering stoichiometric coefficients in enthalpy calculations • Difficulty picking correct method to calculate enthalpy using the information provided in the question ○ Using the wrong equation when using bond enthalpy vs enthalpy of formation • Confusing enthalpy (ΔH) and heat (q) • When calculating the amount of energy to heat a sample and change phase (for example), only using one equation to calculate one step of the process (versus energy required to change temp + energy required to change phase) • Difficulty manipulating given chemical reactions **and** the enthalpy values in order to use Hess's Law to calculate enthalpy of overall process
Connections to Prior Units:	**Connections to Future Units:**
• Students learned about heat transfer, specific heat and specific heat calculations, and phase changes in Physical Science • Energy reaction profiles were introduced in Unit 5. Now students can compare reactants and products to determine if overall reaction is endothermic or exothermic	• Hess's law manipulations are similar but different to how you can manipulate equilibrium constant K in Units 7, 8, and 9 • ΔH returns in Unit 9 to determine if a reaction is thermodynamically favorable or not. • Activation energy can help determine why a thermodynamically favorable reaction may not occur at appreciable rates (9.4)
Differentiation through *Universal Design for Learning*	

	Engagement	Representation	Action & Expression
LT1	Hand warmer (exothermic) and cold pack (endothermic) exploration observing temperature changes during transformations.	Classification chart linking temperature increase (ΔT > 0 -> Exothermic, ΔH < 0) and temperature decrease (ΔT < 0 -> Endothermic, ΔH > 0).	Classify physical or chemical processes as endothermic or exothermic based on lab observations and write an energy flow explanation.
LT2	"Energy Curve Builder" drawing system energy changes for dissolution, phase changes, and reactions.	Reaction coordinate energy diagrams labeling system initial energy state, final energy state, and net heat enthalpy change (ΔH).	Draw energy diagrams for physical phase changes or chemical reactions and label system vs. surroundings heat flow.
LT3	Thermal equilibrium simulation observing heat transfer from hot metal blocks to cold water via kinetic particle collisions.	Particulate collision diagrams showing fast-moving high-T particles transferring kinetic energy to slower-moving low-T particles until thermal equilibrium.	Explain zeroth law/thermal equilibrium principles using particulate collision models via written descriptions or oral presentations.
LT4	Coffee-cup calorimetry lab calculating heat capacity (c) of metal washers or enthalpy of neutralization.	Calorimetry formula scaffold ($q = mc\Delta T$) with sign conventions ($q_{sys} = -q_{surr}$) and unit cancellation guides.	Calculate heat exchange and specific heat values from experimental calorimetry data using handwritten solutions or spreadsheets.
LT5	Heating curve lab for water or lauric acid analyzing plateau regions where energy breaks intermolecular forces.	Annotated heating/cooling curve graph (X-axis: heat added; Y-axis: temperature) paired with $q = n \times \Delta H_{phase}$ calculations.	Calculate heat required for multi-step phase transitions (e.g., ice at -10°C to steam at 110°C) and present worked steps.
LT6	Stoichiometric heat calculation challenge converting grams of limiting reactant to kilojoules of heat produced or absorbed.	Stoichiometric conversion bridge: Mass -> Moles -> Heat ($q = n \times \Delta H_{rxn}$).	Solve reaction enthalpy stoichiometry problems by submitting BCA tables, dimensional analysis steps, or video walkthroughs.
LT7	"Bond Energy Accounting" breaking Lewis structure bonds (endothermic input) and assembling new product bonds (exothermic output).	Bond energy formula scaffold: $\Delta H_{rxn} = sum(BE_{broken}) - sum(BE_{formed})$ with structural Lewis model visual cues.	Calculate ΔH_{rxn} using average bond energy tables by drawing Lewis structures for all species and tracking broken/formed bonds.
LT8	Heat of formation calculation challenge comparing theoretical reaction enthalpies across fuel combustion reactions.	Standard enthalpy formula scaffold: $\Delta H^\circ_{rxn} = sum(n \times \Delta H^\circ_f(products)) - sum(m \times \Delta H^\circ_f(reactants))$ with element baseline rules ($\Delta H^\circ_f = 0$).	Calculate ΔH°_{rxn} from standard enthalpy of formation tables for chemical reactions and present worked solution sets.
LT9	"Hess's Law Puzzle" rearranging and flipping elementary chemical equations to align with a target overall reaction.	Step-by-step Hess's Law rules card (Flip reaction -> change sign of ΔH; Multiply coefficients -> multiply ΔH).	Manipulate and sum target chemical equations and their corresponding ΔH values to build overall reaction pathways on whiteboards.
LT10	Hess's Law experimental verification lab combining two reactions (e.g., NaOH dissolution and neutralization) to yield a third.	Algebraic visual showing state function properties where $\Delta H_{overall} = \Delta H1 + \Delta H2 + \Delta H3$ regardless of path.	Write a formal lab report or record a video verifying Hess's Law experimentally by summing multi-step reaction enthalpies.

Supporting Multilingual/English Learners (*CELP standards*)

	Emerging	Expanding	Bridging
LT1	Classify reactions as exothermic (Delta H < 0, feels hot) or endothermic (Delta H > 0, feels cold) using visual cards.	Describe energy changes during transformations using structured paragraph frames ("*Energy is absorbed/released because...*").	Relate macroscopic temperature observations to microscopic enthalpy changes (Delta H) and system-surrounding heat flow.
LT2	Draw simple enthalpy diagrams showing reactant and product energy levels for exothermic and endothermic processes.	Sketch energy diagrams for phase changes and chemical reactions, labeling Delta H using guided prompts.	Construct accurate enthalpy level diagrams for physical and chemical transformations, justifying relative energy levels.
LT3	Draw arrows showing heat transfer from hot objects (fast particles) to cold objects (slow particles).	Explain thermal equilibrium and heat transfer using particle collision sentence starters ("*Faster particles collide with...*").	Explain the zeroth law and kinetic thermal energy transfer at the particulate level, detailing how thermal equilibrium is reached.

LT4	Calculate heat using q = m * c * Delta T with formula variable cards and unit templates.	Solve calorimetry problems (q_system = -q_surroundings) using step-by-step calculation frames.	Analyze coffee-cup or bomb calorimetry data to calculate q, molar enthalpy changes, and specific heat capacities.
LT5	Identify heating curve plateaus as phase changes where temperature remains constant.	Calculate heat required for phase changes (q = n * Delta H_fusion/vap) using step-by-step calculation templates.	Perform multi-step heating/cooling curve calculations combining q = m * c * Delta T and q = n * Delta H across phase transitions.
LT6	Calculate heat released using dimensional analysis templates (moles * Delta H_rxn).	Calculate reaction heat for given reactant amounts using stoichiometry and enthalpy conversion frames.	Solve stoichiometry-enthalpy problems involving limiting reactants and calculate molar enthalpy of reaction (Delta H_rxn).
LT7	List bonds broken and bonds formed in a reaction table using Lewis structure representations.	Calculate Delta H_rxn using sum(Bonds Broken) - sum(Bonds Formed) formula templates.	Calculate reaction enthalpies from bond energies, explaining why bond-energy calculations are estimates compared to Delta Hf°.
LT8	Locate Delta Hf° values in a reference table and plug into sum(n * Delta Hf°(products)) - sum(m * Delta Hf°(reactants)).	Calculate Delta H_rxn° using standard formation values and structured equation templates.	Compute standard reaction enthalpies using formation data, explaining why Delta Hf° for pure elements in standard states is zero.
LT9	Rearrange chemical equation cards to show how individual steps sum to an overall target equation.	Combine intermediate reaction steps to yield an overall reaction equation using guided step-by-step rules.	Formulate logical reaction sequences that represent complex transformations, verifying stoichiometry and species cancellation.
LT10	Calculate total Delta H by adding given Delta H values of intermediate steps on a visual diagram.	Apply Hess's Law to flip or multiply reaction steps and calculate overall Delta H using guided templates.	Execute multi-step Hess's Law calculations, manipulating reaction equations and their corresponding Delta H values with full justifications.

Unit Overview

The ability to link atomic- and particulate level phenomena and models to macroscopic phenomena is central to the study of chemistry. In previous units, students used representations, equations, and reasoning to demonstrate this ability. In Unit 6, students will develop justifications for claims made about the direction of thermal energy transfer of a system in relation to its surroundings when a temperature change, physical change, or a chemical reaction occurs. Students will construct representations of energy using appropriate diagrams with arrows showing the direction of energy transfer between the system and the surroundings. They will continue to develop their explanations of chemical phenomena by explaining how the change in energy of a system is balanced by transfer of energy by either heat or work into or out of the system.

Lesson	Learning Target	Success Criteria	Suggested Activities
6.1 Endothermic and Exothermic Processes	**Learning Target 1** I can explain the relationship between experimental observations and energy changes associated with chemical and physical transformations.	• I can use temperature changes in a system to infer whether energy has been absorbed or released. • I can describe energy changes in terms of endothermic and exothermic processes, including heating/cooling, phase changes, and chemical reactions. • I can explain that in exothermic processes energy is transferred from the system to the surroundings, and in endothermic processes energy is transferred from the surroundings to the system. • I can explain how the formation of a solution can be either endothermic or exothermic depending on the relative strengths of interactions	**Think-Pair-Share** Have student pairs generate a list of exothermic and endothermic processes that occur in their everyday life. Have them share their lists with other pairs to determine if they have correctly identified these common processes in terms of endo- or exothermicity.

		broken and formed during dissolution.	
6.2 Energy Diagrams	**Learning Target 2** I can represent a chemical or physical transformation using an energy diagram.	• I can use an energy diagram to show whether a process is endothermic or exothermic. • I can interpret energy diagrams to describe changes in energy during a physical or chemical process.	**Think-Pair-Share** (see 6.1)
6.3 Heat Transfer and Thermal Equilibrium	**Learning Target 3** I can explain the relationship between the transfer of thermal energy and molecular collisions.	• I can describe how particles in a warmer substance have greater average kinetic energy than particles in a cooler substance. • I can explain how collisions between particles in thermal contact result in the transfer of energy as heat. • I can describe how energy transfer continues through particle collisions until thermal equilibrium is reached. • I can explain that at thermal equilibrium, the average kinetic energy and temperature of both systems are equal.	**Demo with Q&A** After working a few practice problems in groups with the q = mcΔT equation, demonstrate that heating 40 g of copper pellets to 80°C and placing them into 40 g of 20°C water does not result in 50°C as a final temperature. Have students reason why and then record the final temperature of the copper/water mixture. Then have them calculate the specific heat capacity of copper and compare it to published values. As a class discussion, account for deviations from the expected results.
6.4 Heat Capacity and Calorimetry	**Learning Target 4** I can calculate the heat (q) absorbed or released by a system using the equation q = mcΔ T.	• I can explain how calorimetry experiments are used to measure heat transfer between a system and its surroundings. • I can apply the first law of thermodynamics to explain that energy is conserved during heating and cooling processes. • I can explain why equal masses of different substances experience different temperature changes when the same amount of heat is transferred. • I can describe how specific heat capacity and molar heat capacity are used in calculations involving thermal energy transfer. • I can explain that chemical systems change energy through heating/cooling, phase transitions, and chemical reactions. • I can describe how calorimetry can be used to determine the direction of energy flow during a process. • I can explain that an increase in temperature of a solution indicates that the process is exothermic and releases thermal energy. • I can explain that a decrease in temperature of a solution indicates that the process is endothermic and absorbs thermal energy.	**Process Oriented Guided Inquiry Learning (POGIL)** Have students wet one finger with water and keep one finger dry then wave them in the air to see which feels cooler. Have them respond to a series of guided questions about the energy transfers involved in the evaporation process. Next, two beakers are heated side by side on a hot plate. Heating a beaker with 100 g of water on the same hot plate alongside a beaker with 100 g of 1-propanol results in very different changes in temperature. Through guided inquiry, students derive the concept of specific heat. As a class, compare whether the two liquids have been treated “fairly,” and the concept of molar heat capacity is established and compared to specific heat capacity.

6.5 Energy of Phase Changes	**Learning Target 5** I can explain changes in heat (q) absorbed or released during a phase transition using the amount of substance in moles and the molar enthalpy of the phase change.	• I can describe how energy must be absorbed for melting and vaporization, increasing the system's energy, and how energy is released during freezing and condensation, decreasing the system's energy. • I can explain why the temperature of a pure substance remains constant during a phase change even though energy is being transferred. • I can calculate the heat involved in a phase change using molar enthalpy and moles of substance. • I can explain that the energy absorbed in one direction of a phase change is equal in magnitude and opposite in sign to the energy released in the reverse process (e.g., fusion vs. freezing, vaporization vs. condensation).	
6.6 Introduction to Enthalpy of Reaction	**Learning Target 6** I can calculate the heat (q) absorbed or released by a system undergoing a chemical reaction using the amount of reacting substance in moles and the molar enthalpy of reaction.	• I can explain that the enthalpy change of a reaction represents the heat released (negative ΔH) or absorbed (positive ΔH) at constant pressure. • I can describe how energy is transferred between a system and its surroundings during exothermic and endothermic reactions to reach thermal equilibrium. • I can explain that changes in chemical potential energy during reactions result from breaking and forming bonds, which leads to a change in the kinetic energy of particles.	
6.7 Bond Enthalpies	**Learning Target 7** I can calculate the enthalpy change of a reaction using average bond energies of bonds broken and bonds formed.	• I can explain that chemical reactions involve breaking bonds in reactants and forming new bonds in products, which changes the system's potential energy. • I can estimate the total energy required to break reactant bonds by summing the average bond energies of all bonds broken. • I can estimate the total energy released when product bonds form using average bond energies. • I can determine whether a reaction is exothermic or endothermic by comparing the energy required to break bonds with the energy released when bonds form.	**Think-Pair-Share** Have pairs of students examine tables of average bond enthalpy and establish patterns with regard to bond order, atomic radius, and bond length. Similar patterns are examined for the standard enthalpies of formation. Have student pairs work through several practice problems using bond energies and enthalpies of formation to determine the enthalpy of a chemical reaction and compare their calculations.
6.8 Enthalpy of Formation	**Learning Target 8** I can calculate the enthalpy change for a chemical or physical process using standard enthalpies of formation.	• I can use tabulated standard enthalpies of formation to determine the overall enthalpy change of a reaction. • I can apply the equation $\Delta H^\circ_{reaction} = \Sigma \Delta Hf^\circ_{products} - \Sigma \Delta Hf^\circ_{reactants}$ to calculate reaction enthalpy.	**Think-Pair-Share** (see 6.7)
6.9 Hess's Law	**Learning Target 9** I can represent a chemical or physical process as a sequence of steps.	• I can explain that many processes can be broken down into a series of steps, each with its own energy change. • I can describe how the overall energy change of a process is related to the sum of the energy changes of its individual steps.	**Post-Lab Discussion** Have students apply Hess's law by reacting magnesium metal and magnesium oxide with hydrochloric acid to determine the enthalpy change of the following reaction: Mg + O 2 → MgO. Then have them evaluate their results and discuss sources of error.
	Learning Target 10 I can explain that the enthalpy of a chemical	• I can describe how energy is conserved in a multi-step process, so the total enthalpy change equals the net energy transferred to or from the surroundings.	

	or physical process is equal to the sum of the enthalpies of its individual steps.	● I can explain that at constant pressure, the overall enthalpy change is the sum of the enthalpy changes of each step in a reaction sequence. ● I can apply Hess's Law to calculate enthalpy changes by reversing reactions (changing the sign of ΔH), multiplying reactions (scaling ΔH accordingly), and adding reactions together to obtain an overall ΔH.

Progress Check 6

- Multiple-choice: ~20 questions
- Free-response: 2 questions
    - Short
    - Short

Preparing for the AP Exam

On the AP Exam, students must be able to translate between a balanced chemical reaction and a calculation involving the energies of bonds broken and bonds formed within the reaction. In addition, students will be required to analyze calorimetry data and apply mathematical routines to calculate or estimate the heat transferred and the overall enthalpy of a reaction. In a question that asks students to apply mathematical routines to estimate or calculate the overall enthalpy of a reaction, students often struggle to determine the number of bonds that were broken and made in the reaction. Teachers can ensure that students are able to identify the bonds broken and formed in the reaction and use the enthalpies for such to determine the overall enthalpy for the reaction, in addition to their ability to represent a chemical reaction with its associated equation.

Unit Title:

Unit 7: Equilibrium

Relevant Standards: Bold indicates priority

7.1 Introduction to Equilibrium: Students can use chemical principles and mathematical reasoning to justify claims about dynamic equilibrium in reversible reactions, including the relationship between forward and reverse reaction rates.

7.2 Direction of Reversible Reactions: Students can explain how particulate-level interactions connect to macroscopic behavior in reversible reactions and use representations to determine the direction a reaction will proceed.

7.3 Reaction Quotient and Equilibrium Constant: Students can represent chemical equilibrium systems using mathematical expressions and graphs, and interpret the reaction quotient (Q) in relation to the equilibrium constant (K).

7.4 Calculating the Equilibrium Constant: Students can calculate equilibrium constants from experimental data and explain how changes in system variables affect equilibrium relationships.

7.5 Magnitude of the Equilibrium Constant: Students can use chemical principles and mathematical reasoning to justify how the magnitude of K relates to the extent of a reaction at equilibrium.

7.6 Properties of the Equilibrium Constant: Students can identify and apply the mathematical relationships and definitions required to determine equilibrium constants from given chemical information.

7.7 Calculating Equilibrium Concentrations: Students can calculate equilibrium concentrations or partial pressures using appropriate mathematical models, including ICE tables, and represent results clearly using correct units and precision.

7.8 Representations of Equilibrium: Students can construct and interpret particulate, graphical, and symbolic representations of equilibrium systems across multiple scales to show the relationship between structure and observable properties.

7.9 Introduction to Le Châtelier's Principle: Students can explain how experimental observations of equilibrium systems support Le Châtelier's Principle and relate shifts in equilibrium to changes in conditions.

7.10 Reaction Quotient and Le Châtelier's Principle: Students can predict the direction of a system's shift toward equilibrium by comparing Q and K and applying quantitative reasoning to equilibrium changes.

7.11 Introduction to Solubility Equilibria: Students can select and apply appropriate equilibrium relationships to solve problems involving solubility equilibria.

7.12 Common-Ion Effect: Students can explain how modifications to a system (such as addition of a common ion) alter equilibrium position and solubility based on equilibrium principles.

Essential Question(s):	**Enduring Understanding(s):**
1. How are the rates of forward and reverse reactions related to the direction that a reversible reaction proceeds? 2. How can the composition of a mixture at equilibrium be predicted? 3. How can an equilibrium system be manipulated to maximize product yield? 4. Why do paramedics administer pure oxygen to people with carbon monoxide poisoning? 5. What factors influence the degree to which a salt will dissolve?	1. Some reactions can occur in both forward and reverse directions, sometimes resulting in a dynamic equilibrium state. 2. A system at equilibrium depends on the relationships between concentrations, partial pressures of chemical species, and the equilibrium constant K. 3. Systems at equilibrium respond to external stresses to offset the effect of the stress. 4. The dissolution of a salt is a reversible process that can be influenced by environmental factors such as pH or other dissolved ions.
Demonstration of Learning:	**Pacing for Unit**
• Success with unit MCQs and FRQs via AP Classroom	10 instructional days

• Quizzes (AP Classroom MCQs and FRQs) every few topics • K vs Q particle modeling • Practice RICE calculations • Practice writing out equilibrium expressions • Practice calculating the effect of a common ion and responding to FRQ questions about common ion effect • Solubility of Calcium Chloride Lab (Ksp) • Progress Check 7 from AP Classroom Unit 7 is 7-9% of AP Exam Weighting See AP Exam Description	2 days for lab 2 days for review / assess
Family Overview (link below)	**Integration of Technology:**
AP Chemistry FAMILY MATERIALS	N/A
Unit-specific Vocabulary:	**Aligned Unit Materials, Resources, and Technology (beyond core resources):**
Equilibrium, chemical equilibrium, dynamic equilibrium, Le Chatelier's principle, equilibrium constant (K), reaction quotient (Q), heterogeneous equilibrium, homogeneous equilibrium, partial pressure, Kp, Kc, relationship between Kp and Kc, concentration changes, pressure changes, temperature changes, catalyst effect on equilibrium, solubility equilibrium, solubility product constant (Ksp), ion product (Qsp), common ion effect, precipitation, dissolution, saturated solution, unsaturated solution, supersaturated solution	• Stir plates • Milk of magnesia • Application of spectrophotometer if we had one • Pop beads and petri dishes to model K and Q
Opportunities for Interdisciplinary Connections:	**Anticipated misconceptions:**

• Biology: homeostasis and dynamic equilibrium in body systems
• Environmental Science: ocean acidification and atmospheric equilibrium
• Medicine: oxygen transport and blood chemistry equilibria
• Engineering: industrial equilibrium processes such as ammonia synthesis
• Mathematics: modeling dynamic systems and equilibrium calculations
	• Confusing rate constant k and equilibrium constant K
	• Writing out equilibrium expression incorrectly
	  ○ Including solids or liquids in equilibrium expression
	  ○ Putting products on the bottom
	  ○ Not including stoichiometry coefficients as superscripts
	  ○ Using K_c vs K_p when appropriate. Writing out the two equilibrium expressions with appropriate notation
	• Inappropriate or insufficient language to describe impact of stressor
	  ○ Shift left or right vs towards reactants or products vs proceed forwards or in reverse direction
	  ○ Using comparison of reaction quotient Q and equilibrium constant K to justify answer for Le Chatelier's or common ion effect
	• Using incorrect units in RICE table
	• Misuse of 5% approximation

Connections to Prior Units:	**Connections to Future Units:**
• Students must be able to determine how an ionic compound will dissolve and write out net ionic equation (4.2) • Students must be able to calculate molarity of solutions (3.7) • Students must be able calculate partial pressures to use in a K_p expression (3.4)	• Equilibrium expressions and RICE tables are used in unit 8 with equilibrium of weak acid or weak base in water • Effect of pH on solubility is included in Unit 8 • Equilibrium constant K can be used with electrochemical calculations to determine if a cell will be thermodynamically favorable or not (unit 9)

• Students must be able to reference reaction rates and catalysts to determine how a catalyst impacts equilibrium	

Differentiation through *Universal Design for Learning*

	Engagement	Representation	Action & Expression
LT1	Reversible reaction lab observing color shifts in the CoCl4^2- / [Co(H2O)6]^2+ system upon heating and cooling.	Dynamic equilibrium visual showing non-zero forward and reverse rates maintaining constant macroscopic concentrations.	Write a description or record a video explaining how dynamic equilibrium differs from a static reaction ending point.
LT2	Rate vs. Time graph exploration showing forward rate decreasing and reverse rate increasing until r_forward = r_reverse.	Side-by-side graph comparison displaying Rate vs. Time and Concentration vs. Time (concentrations plateau).	Interpret Rate vs. Time and Concentration vs. Time graphs to identify when equilibrium is established in a reversible system.
LT3	Writing equilibrium expressions for heterogeneous reactions containing pure solids and liquids.	Mass action expression guide: Q_c = ([C]^c [D]^d) / ([A]^a [B]^b), emphasizing exclusion of pure solids (s) and liquids (l).	Write correct Q_c and Q_p expressions for homogeneous and heterogeneous chemical systems on problem sets or digital whiteboards.
LT4	Equilibrium constant calculation lab analyzing the formation of FeSCN^2+ using spectrophotometry data.	Equilibrium calculation formula card converting equilibrium concentrations/pressures into numerical K_c or K_p values with K_p = K_c(RT)^Δn.	Calculate K_c or K_p values from equilibrium measurement data and convert between K_c and K_p using worked solutions.
LT5	"Product-Favored vs. Reactant-Favored Sorting" matching K values (K >> 1, K ≈ 1, K << 1) to mixture composition images.	Visual scale mapping K > 10^3 (product-dominated at equilibrium) vs. K < 10^-3 (reactant-dominated at equilibrium).	Analyze given K values and state whether reactants or products dominate at equilibrium, supporting claims with mathematical justifications.
LT6	Multi-step equilibrium puzzle calculating K_overall by multiplying step constants (K_overall = K1 × K2).	Summary rules card for manipulating K: Reverse reaction -> 1/K; Multiply coefficients by n -> K^n; Add reactions -> K1 × K2.	Calculate K for modified or multi-step equilibrium equations using mathematical rules and present step-by-step work.
LT7	"RICE Table Challenge" solving for equilibrium concentrations given initial values and K (including 5% approximation rule).	RICE table template (Reaction, Initial, Change, Equilibrium) with algebraic variable guides.	Solve equilibrium concentrations using RICE tables and validate or refute 5% approximation assumptions via written problem sets.
LT8	Particulate box counting activity verifying whether a particle diagram matches the ratio specified by K.	Particulate box diagrams displaying molecular counts before and at equilibrium, confirming constant particle ratios.	Draw particulate representations of an equilibrium mixture matching a specific K value and defend particle count ratios.
LT9	Le Châtelier's principle lab applying stress (concentration change, temperature shift, volume/pressure change) to equilibrium systems.	Stress-Response summary matrix detailing system shifts: Add reactant -> shift right; Increase T (exothermic) -> shift left; Decrease V -> shift to fewer gas moles.	Predict shift direction for equilibrium systems subjected to external stresses and defend predictions using Le Châtelier's principle.
LT10	"Q vs. K Number Line" comparing calculated Q values against K to determine net reaction direction.	Number line visual comparison: Q < K (shift right ->), Q = K (at equilibrium), Q > K (shift left <-).	Calculate Q, compare it to K, and write a justification stating which direction the system must shift to reach equilibrium.
LT11	Molar solubility calculation challenge computing dissolved ion concentrations for sparingly soluble salts (e.g., AgCl, PbI2).	K_sp expression scaffold [K_sp = [M^n+]^m [X^m-]^n] paired with molar solubility (x) substitution equations.	Calculate molar solubility (x) and ion concentrations from K_sp values for 1:1, 1:2, and 1:3 sparingly soluble salts.
LT12	"Common Ion Effect Lab" adding NaCl to a saturated PbCl2 solution to observe increased precipitation.	Le Châtelier K_sp visual diagram showing how adding a common ion shifts solubility equilibrium left, decreasing molar solubility.	Calculate reduced molar solubility of a salt in the presence of a common ion and explain the shift using K_sp expressions.

Supporting Multilingual/English Learners (*CELP standards*)

	Emerging	Expanding	Bridging

LT1	Identify equilibrium on a concentration vs. time graph as the point where concentrations become constant.	Explain dynamic equilibrium using sentence starters (*"At equilibrium, the forward rate equals..."*).	Describe dynamic chemical equilibrium, emphasizing equal forward/reverse rates and constant macroscopic properties.
LT2	Compare forward and reverse rate arrows on a visual diagram before and at equilibrium.	Explain how unequal forward and reverse rates shift species concentrations toward equilibrium using guided prompts.	Analyze rate vs. time graphs to evaluate how non-equilibrium systems adjust forward and reverse rates to achieve dynamic equilibrium.
LT3	Write equilibrium expressions (K = [Products] / [Reactants]) using visual formula templates (excluding solids/liquids).	Write Qc and Qp expressions for balanced reversible reactions using structured graphic organizers.	Formulate correct Qc and Qp expressions for heterogeneous and homogeneous equilibria, justifying why pure solids/liquids are omitted.
LT4	Calculate K by plugging given equilibrium concentrations directly into a provided K expression.	Calculate Kc or Kp from equilibrium data using structured calculation templates and ICE tables.	Calculate equilibrium constants (Kc, Kp) from initial conditions and partial equilibrium data using ICE tables and unit analysis.
LT5	Classify reactions as "product-favored" (K > 1) or "reactant-favored" (K < 1) using visual scale cards.	Explain what K >> 1 or K << 1 implies about equilibrium composition using structured sentence frames.	Interpret the physical significance of K magnitudes, relating K values to reaction extent and thermodynamic favorability.
LT6	Combine K values of combined steps using the rule: K_overall = K1 * K2 on a visual template card.	Calculate overall K for combined reactions (reversing, multiplying coefficients) using rule-based calculation guides.	Derive overall equilibrium expressions and calculate K_overall for manipulated multi-step equilibrium systems.
LT7	Set up an ICE (Initial, Change, Equilibrium) table grid using provided initial concentrations and +x / -x hints.	Solve ICE table problems for equilibrium concentrations using algebraic templates and the 5% approximation rule.	Calculate equilibrium concentrations or partial pressures using ICE tables, solving quadratic equations or applying the 5% rule when valid.
LT8	Count reactant and product particles in box diagrams to determine if a system is at equilibrium.	Construct particulate diagrams representing systems before, during, and at equilibrium using ratio guidelines.	Draw and evaluate particulate models of equilibrium mixtures, ensuring particle counts reflect K magnitudes and stoichiometry.
LT9	Predict response direction (Shift Left/Right) when adding/removing species using a visual seesaw diagram.	Predict equilibrium shifts due to concentration, pressure, volume, or temperature changes using Le Châtelier sentence frames.	Apply Le Châtelier's principle to predict and explain shifts, species concentration changes, and K value changes (for T changes).
LT10	Compare Q and K on a number line card (Q < K -> shift right; Q > K -> shift left).	Explain reaction direction shifts by comparing Q to K using structured writing templates (*"Since Q < K, the system must..."*).	Calculate Q, compare it to K, and mathematically explain why the system proceeds forward or reverse to restore equilibrium.
LT11	Write Ksp expressions for simple ionic salts using visual dissociation equation templates.	Calculate molar solubility (s) or Ksp using structured ICE tables and formula templates.	Calculate molar solubility, mass solubility, and Ksp for various salts, accounting for stoichiometry and polyatomic ions.
LT12	Identify the "common ion" in a mixture using color-coded chemical formula cards.	Explain why adding a common ion decreases solubility using Le Châtelier sentence starters.	Calculate molar solubility of a salt in the presence of a common ion using ICE tables and Ksp expressions.

Unit Overview

Building on practices from earlier units where students translated between representations of chemical systems, they will now construct equilibrium expressions from reaction equations. Students should also illustrate the dynamic nature of the chemical reaction through particulate level representations, portraying both the forward and reverse rates of the reaction equations. They will construct and describe graphs that represent a chemical system in equilibrium and connect them to their particulate-levelrepresentationsand equilibrium expressions. In conjunction with their constructed equilibrium expressions, students will practice using experimental data to calculate the reaction quotient (Q) and equilibrium constant (K) for a reaction. Using Le Châtelier's principle, they will also support claims made about the dominant direction of a reaction once stresses like changes in concentration, pressure, volume, or temperature are introduced.

Lesson	Learning Target	Success Criteria	Suggested Activities

7.1 Introduction to Equilibrium	**Learning Target 1** I can explain the relationship between reversible chemical or physical processes and the establishment of equilibrium using experimental observations.	• I can identify examples of reversible processes, including phase changes, gas exchange, dissolution/precipitation, acid–base reactions, and redox reactions. • I can describe equilibrium as a state where reactants and products are both present and their concentrations or partial pressures remain constant over time. • I can explain that chemical equilibrium is dynamic, meaning forward and reverse reactions continue to occur at equal rates with no net observable change. • I can interpret graphs of concentration, partial pressure, or reaction rate versus time to determine when equilibrium has been established.	
7.2 Direction of Reversible Reactions	**Learning Target 2** I can explain the relationship between the direction a reversible reaction proceeds and the relative rates of the forward and reverse reactions.	• I can describe how a faster forward reaction than reverse reaction results in a net formation of products. • I can describe how a faster reverse reaction than forward reaction results in a net formation of reactants. • I can explain that equilibrium is reached when the forward and reverse reaction rates are equal, resulting in no net change in concentrations.	
7.3 Reaction Quotient and Equilibrium Constant	**Learning Target 3** I can represent the reaction quotient (Q) for a reversible reaction using the relative concentrations or partial pressures of reactants and products.	• I can explain that the reaction quotient describes the ratio of product species to reactant species at any point in time, based on their concentrations or partial pressures. • I can distinguish between Qc (based on concentration) and Qp (based on partial pressure) for gas-phase reactions. • I can explain that the equilibrium constant (K) has the same mathematical structure as the reaction quotient but applies specifically when the system is at equilibrium. • I can explain that as a reaction approaches equilibrium, the value of Q changes until it becomes equal to K, at which point the system is at equilibrium.	**Manipulatives** Give groups of students containers that hold objects representing particles in an equilibrium mix (beads work well here). Each bead represents a molecule in a reversible synthesis reaction. The law of mass action is introduced, and students are asked to calculate K. Each group should get the same value for K, even though the number of particles in each container is different. Each group of students then gets a new container that represents a mixture not at equilibrium, and they calculate the ratio using the law of mass action. The concept of Q is introduced and then students determine if and how they could get the ratio of reactants and products to be equal to K by attaching or detaching beads.
7.4 Calculating the Equilibrium Constant	**Learning Target 4** I can calculate the equilibrium constant (Kc or Kp) using experimental measurements of concentrations or partial pressures at equilibrium.	• I can determine equilibrium constant values from data collected once a reaction has reached equilibrium. • I can apply equilibrium data to quantify the relative amounts of reactants and products in a system at equilibrium.	**Identify Subtasks** Given a gaseous equilibrium process, have students construct the expression that can ultimately be used to calculate the K_p.

7.5 Magnitude of the Equilibrium Constant	**Learning Target 5** I can explain the relationship between the magnitude of the equilibrium constant (K) and the relative amounts of reactants and products at equilibrium.	• I can describe that very large K values indicate that products are favored and the reaction proceeds nearly to completion. • I can describe that very small K values indicate that reactants are favored and very little product is formed. • I can use the value of K to predict whether a reaction mixture at equilibrium contains mostly reactants, mostly products, or a significant amount of both.	**Identify Subtasks** (See 7.4)
7.6 Properties of the Equilibrium Constant	**Learning Target 6** I can represent a multistep process using an overall equilibrium expression derived from the equilibrium expressions of each individual step.	• I can explain that reversing a reaction inverts the value of the equilibrium constant. • I can explain that multiplying a reaction by a factor changes the equilibrium constant by raising it to that same power. • I can explain that adding multiple reactions together results in an overall equilibrium constant equal to the product of the individual equilibrium constants. • I can apply the same algebraic rules used for equilibrium constants to reaction quotients because they share the same mathematical form.	
7.7 Calculating Equilibrium Concentrations	**Learning Target 7** I can identify the concentrations or partial pressures of chemical species at equilibrium using the balanced equation, initial conditions, and the equilibrium constant (K).	• I can predict whether a reaction will shift toward products or reactants by comparing the reaction quotient (Q) to the equilibrium constant (K). • I can explain that when Q < K, the reaction shifts toward products, consuming reactants. • I can explain that when Q > K, the reaction shifts toward reactants, consuming products. • I can explain that when Q = K, the system is at dynamic equilibrium with no net change in concentrations or partial pressures.	
7.8 Representations of Equilibrium	**Learning Target 8** I can represent a system undergoing a reversible reaction using a particulate model.	• I can use particulate diagrams to show the relative numbers of reactant and product particles before equilibrium is reached. • I can use particulate models to represent the composition of a system at equilibrium. • I can connect particulate representations to the magnitude of the equilibrium constant to describe whether reactants or products are favored.	
7.9 Introduction to Le Châtelier's Principle	**Learning Target 9** I can identify how a system at equilibrium responds to external stresses using Le Châtelier's principle.	• I can predict how adding or removing a chemical species shifts the position of equilibrium. • I can predict how changes in temperature affect the direction of a shift in equilibrium. • I can predict how changes in volume or pressure affect gas-phase equilibrium systems. • I can explain how dilution affects the equilibrium position in a solution. • I can use Le Châtelier's principle to predict changes in observable properties such as pH, temperature, and color.	**Demo with Q&A** Prepare a solution of cobalt (II) chloride in dry ethanol. Demonstrate various methods to shift the equilibrium position: adding water, heating, cooling, layering with dry acetone, adding silver nitrate to precipitate chloride ions from solution, and measuring the temperature change of the solution as concentrated hydrochloric acid is added. As a class, have students analyze what each change does to the predominant species in the equilibrium mixture and then generalize patterns for LeChâtelier's

			principle.
7.10 Reaction Quotient and Le Châtelier's Principle	**Learning Target 10** I can explain the relationship between Q, K, and the direction a reversible reaction will proceed to reach equilibrium.	• I can describe how a disturbance to a system at equilibrium causes Q to differ from K, shifting the system out of equilibrium. • I can explain that the system responds by shifting the reaction forward or reverse until Q again equals K. • I can distinguish between changes that affect Q (such as concentration, pressure, or volume changes) and changes that affect K (such as temperature changes). • I can explain how changes in concentration or pressure affect Q, while temperature changes alter the value of K and lead to a new equilibrium state.	**Demo with Q&A** (see 7.9)
7.11 Introduction to Solubility Equilibria	**Learning Target 11** I can calculate the solubility of a salt using its solubility product constant (Ksp).	• I can describe dissolution as a reversible process that reaches equilibrium in saturated solutions. • I can use Ksp values to compare the relative solubility of different salts. • I can relate solubility rules to Ksp values to predict whether a salt is soluble or insoluble. • I can determine Ksp from the molar solubility of a substance in a saturated solution.	**Post-Lab Discussion** After examining the K sp tables for patterns (including ion charge, ionic radius, polyatomic vs. monoatomic ions, etc.), have students investigate the K sp of lead (II) iodide. One drop of 0.1 M potassium iodide is added to 250 mL of 0.01 M lead (II) nitrate. A precipitate forms but then dissolves as it dissipates through the solution. Based on K sp, have students calculate whether the precipitate should have formed and connect this calculation with what was initially observed. Have them determine how many milliliters of the 0.1 M KI solution would need to be added for a lasting precipitate to be formed. Then have them share their calculated values and agree as a class which is the best answer
7.12 Common-Ion Effect	**Learning Target 12** I can identify how the solubility of a salt changes when a common ion is already present in solution.	• I can explain that the presence of a common ion reduces the solubility of a salt by shifting the dissolution equilibrium. • I can use Le Châtelier's principle to predict the direction of shift in a system affected by the common-ion effect. • I can calculate solubility or Ksp values in solutions that already contain a common ion.	

Progress Check 3

- Multiple-choice: ~30 questions
- Free-response: 2 questions
  - Short
  - Long

Preparing for the AP Exam

On the AP Exam, students must be able to connect what is happening at the molecular level to a model for a system at equilibrium. For example, when students are asked to connect the value of the equilibrium constant (K) from the equilibrium expression to the dominant direction of the reaction, they struggle to connect the value of a large K to a

reaction proceeding essentially to completion. This lack of connection leads students to use ineffective mathematical routines and then incorrectly calculate the concentration of the product in solution. To help students avoid this type of misunderstanding, teachers can ensure that students connect the value of the equilibrium constant to the experimental data or observations provided. Additionally, teachers can help students visualize the effects of a large or small equilibrium constant on the concentrations of all species in equilibrium.

Unit Title:

Unit 8: Acids and Bases

Relevant Standards: Bold indicates priority

8.1 Introduction to Acids and Bases: Students can identify and apply appropriate acid–base theories, definitions, and mathematical relationships to solve chemical problems.

8.2 pH and pOH of Strong Acids and Bases: Students can select and apply appropriate mathematical relationships to determine pH and pOH for strong acid and base solutions.

8.3 Weak Acid and Base Equilibria: Students can explain relationships between variables in acid–base equilibrium expressions and predict how changes in one variable affect the system.

8.4 Acid–Base Reactions and Buffers: Students can calculate, estimate, and predict equilibrium quantities in acid–base systems, including buffer solutions, using logical computational pathways and graphical representations.

8.5 Acid–Base Titrations: Students can analyze titration data to determine the concentration of an unknown acid or base and interpret titration curves to identify key equivalence and buffering regions.

8.6 Molecular Structure of Acids and Bases: Students can use particulate-level representations and molecular structure to support claims about acid and base behavior and justify those claims using chemical principles and data.

8.9 Henderson–Hasselbalch Equation: Students can calculate pH, pOH, or related quantities in buffer systems using the Henderson–Hasselbalch equation with appropriate precision.

8.10 Buffer Capacity: Students can explain how buffer systems resist changes in pH and analyze how experimental conditions and sources of error may affect buffer performance.

8.11 pH and Solubility: Students can interpret experimental data and representations to analyze the relationship between pH and solubility in chemical systems.

Essential Question(s):	**Enduring Understanding(s):**
1. How is pH related to the concentration and strength of an acid, a base, or a mixture of them? 2. How does acid or base strength relate to the concentrations of reactants and products when a system reaches equilibrium? 3. Why are some acids stronger than others? 4. How does your body maintain pH balance?	1. Acid–base behavior can be understood in terms of proton transfer and equilibrium, where the relative strengths of acids and bases determine the extent to which reactants and products are favored. 2. pH and pOH are quantitative measures of hydrogen ion and hydroxide ion concentrations, and they provide a consistent way to describe and compare acidic and basic solutions, including mixtures and buffers. 3. Acid and base strength is directly related to equilibrium position: stronger acids and bases dissociate more completely in water, leading to larger concentrations of products at equilibrium. 4. Buffer systems resist changes in pH because they contain conjugate acid–base pairs that can shift equilibrium to consume added acids or bases. 5. The structure and bonding within molecules influence acid–base behavior, including why some substances act as strong acids or bases while others remain weak.
Demonstration of Learning:	**Pacing for Unit**
• Success with unit MCQs and FRQs via AP Classroom • Quizzes (AP Classroom MCQs and FRQs) every few topics • Practice converting using the pH loop (between pH, pOH, [H+], [OH-] • Practice writing out equilibrium expressions of weak	18 instructional days 4 lab days 3 days for review / assess

acid or base in water • Standardization of NaOH Lab • Determining the Ka of Acetic Acid Lab • Strength of Acids POGIL • Practice predicting the pH of different solutions / different points within a titration • Practice with strong acid/ strong base titration and neutralization calculations • Practice with weak / strong titration and neutralization calculations • Progress Check 8 from AP Classroom Unit 8 is 11-15% See AP Exam Description	
Family Overview (link below)	**Integration of Technology:**
AP Chemistry FAMILY MATERIALS	N/A
Unit-specific Vocabulary:	**Aligned Unit Materials, Resources, and Technology (beyond core resources):**
Acid, base, Brønsted–Lowry acid, Brønsted–Lowry base, Lewis acid, proton donor, proton acceptor, acidic hydrogen, Lewis base, strong acid, weak acid, strong base, weak base, pH, pOH, Ka, Kb, pKa, pKb, percent ionization, hydrolysis, buffer, buffer capacity, titration, equivalence point, half equivalence point, Henderson–Hasselbalch equation	• pH probes with Labquests • Stir plates • Burets • Conductivity tester lightbulb
Opportunities for Interdisciplinary Connections:	**Anticipated misconceptions:**
• Biology: blood pH regulation, digestion, enzyme function • Environmental Science: acid rain, soil chemistry, aquatic ecosystems • Medicine: antacids, buffer systems, pharmaceuticals • Agriculture: soil pH and nutrient availability • Engineering: wastewater treatment and corrosion prevention	• Students must memorize the strong acids and bases in order to correctly determine what a substance will do in water (i.e. dissociate fully or only partially and reach equilibrium) • Difficulty with certain math skills that have not yet been taught in math class (logarithms and 10^x) • Difficulty determining when to use a RICE or BCA table • Picking the incorrect Ka or Kb constant • Misidentifying pH at key points during a titration • When do use calculations vs when to predict based on species in solution • Using insufficient explanations to justify claims on FRQs regarding acid or base strength, buffer capacity • Difficulty gathering important info from a titration curve to use in a calculation or justification of FRQ
Connections to Prior Units:	**Connections to Future Units:**
• Students must be able to write the net ionic equations for the dissolution of acids and bases (4.2) • Students must be able to make solutions and do calculations with concentrations (3.7) • Uses equilibrium expressions and RICE tables introduced in unit 7 • Acid/base neutralization reactions and titrations are introduced in Unit 4 • Students must be able to draw and analyze Lewis structures to determine acidic hydrogens • Electrolytes are introduced in Unit 2 with ionic compounds. In unit 8, students can analyze weak and strong acids and bases based on the percent ionization (and thus, how electrolytic these	N/A

substances are).
- 8.11 uses Le Chatelier's and solubility product constant to predict the solubility of salts in acidic or basic solutions.

Differentiation through *Universal Design for Learning*

	Engagement	Representation	Action & Expression
LT1	Logarithmic scale exploration mapping household liquids (lemon juice, bleach) onto a pH scale.	pH mathematical square visual connecting [H3O+], [OH-], pH, and pOH via 10^-14 and pH + pOH = 14.	Convert between [H3O+], [OH-], pH, and pOH using problem sets, spreadsheets, or video walkthroughs.
LT2	"100% Dissociation Challenge" calculating pH for strong monoprotic/diprotic acids and group 1/2 metal hydroxides.	Complete ionization visual chart: [H3O+] = M_acid for strong monoprotic acids; [OH-] = 2 M_base for Ca(OH)2.	Calculate pH and pOH of strong acid and strong base solutions of varying concentrations with worked steps.
LT3	Weak acid ionization lab measuring pH of acetic acid vs. hydrochloric acid at identical molarities.	Weak acid K_a RICE table scaffold and percent ionization formula.	Calculate K_a/K_b, percent ionization, and pH for weak acids and weak bases using RICE tables and handwritten solutions.
LT4	Stoichiometric neutralization lab mixing strong acid/base combinations and calculating excess reactant pH.	ICF (Initial-Change-Final) mole table scaffold for neutralization stoichiometry followed by V_total molarity conversion.	Solve neutralization stoichiometry problems by submitting ICF tables and calculating final pH based on excess reactant.
LT5	Digital titration curve analysis plotting pH vs. volume of titrant for strong vs. weak acid titrations.	Annotated titration curve diagram labeling initial pH, half-equivalence point (pH = pKa), equivalence point, and buffer region.	Interpret titration curves to identify equivalence point volume, pKa, and unknown acid concentration via written or oral reports.
LT6	Molecular structure comparison analyzing acid strength trends across binary acids (HF vs. HCl) and oxyacids (HClO vs. HClO4).	Structural diagram highlighting bond polarity, bond strength, electronegativity, and conjugate base anion stability.	Write a CER argument explaining why acid strength increases with higher central atom electronegativity and oxygen count in oxyacids.
LT7	Speciation curve analysis evaluating the relative abundance of [HA] vs. [A-] as solution pH changes.	Speciation scale visual: pH < pKa -> [HA] > [A-]; pH = pKa -> [HA] = [A-]; pH > pKa -> [A-] > [HA].	Predict the dominant chemical species in a weak acid solution at specified pH values and support predictions mathematically.
LT8	"Buffer Resistance Lab" adding strong acid/base drops to water vs. a buffered solution while monitoring pH.	Particulate reaction diagram showing buffer action: added H+ consumed by A-; added OH- consumed by HA.	Draw particulate diagrams illustrating how a buffer consumes added H+ or OH- ions and write corresponding net ionic equations.
LT9	"Buffer Recipe Lab" mixing calculated volumes of weak acid and conjugate base to hit a target pH.	Henderson-Hasselbalch equation scaffold: pH = pKa + log([A-] / [HA]) with logarithmic ratio rules.	Calculate buffer pH using the Henderson-Hasselbalch equation and design a buffer solution recipe for a specific target pH.
LT10	Buffer capacity stress testing adding large amounts of strong titrant to 0.1 M vs. 1.0 M buffer solutions until capacity fails.	Visual capacity comparison showing high concentration buffers containing more moles of HA and A- to neutralize added stress.	Write an analysis comparing two buffer solutions of identical pH but different concentrations, explaining differences in buffer capacity.
LT11	Dissolution lab adding acid to CaCO3 or Mg(OH)2 precipitates to observe dramatic solubility increases.	Coupled equilibrium visual showing added H+ removing basic anions (CO3^2- or OH-), shifting K_sp right.	Explain why salts containing basic anions become more soluble in acidic solutions using Le Châtelier's principle and coupled equations.

Supporting Multilingual/English Learners (*CELP standards*)

	Emerging	Expanding	Bridging
LT1	Calculate pH from [H3O+] using a pH square chart (pH + pOH = 14) and calculator steps.	Calculate pH, pOH, [H3O+], and [OH-] using formula templates and logarithmic calculation guides.	Convert fluently between pH, pOH, [H3O+], and [OH-] at various temperatures, justifying Kw temperature dependence.

LT2	Identify strong acids/bases from a reference list and set [H3O+] = [Acid]_0 for 1:1 strong acids.	Calculate pH of strong acid and base solutions (accounting for stoichiometry like Ca(OH)2) using calculation templates.	Calculate pH and pOH for single and mixed strong acid/base solutions before reaction, writing complete justifications.
LT3	Identify weak acids/bases as "partially ionized" (<< 100%) using particulate dissociation diagrams.	Calculate pH or Ka/Kb for weak acids/bases using structured ICE tables and percent ionization templates.	Solve weak acid/base equilibrium problems, calculating Ka, Kb, pH, and percent ionization, verifying the 5% approximation.
LT4	Identify excess reactant (acid or base) in a neutralization reaction using BCA table templates.	Calculate pH after mixing strong acids and bases using structured stoichiometry (BCA) tables and excess volume frames.	Calculate equilibrium pH and all major species concentrations following complete or partial neutralization reactions.
LT5	Label key points on a titration curve (initial pH, half-equivalence, equivalence point) using a visual guide.	Explain titration curve features (buffer region, equivalence point pH) using structured comparison templates.	Interpret mono- and polyprotic titration curves, calculating Ka from pH = pKa at half-equivalence and explaining pH at equivalence.
LT6	Match acid strength to electronegativity or bond strength trends using visual structural formula cards.	Explain acid strength trends (binary acids, oxyacids) using bond strength and electronegativity sentence frames.	Justify relative strengths of binary acids and oxyacids based on bond polarity, bond strength, and conjugate base resonance stabilization.
LT7	Select dominant species ([HA] > [A-] or [A-] > [HA]) using a pH vs. pKa number line card.	Determine major species in solution by comparing pH to pKa using structured conditional sentence frames.	Predict and justify dominant conjugate species concentrations at any given pH using the Henderson-Hasselbalch relationship.
LT8	Identify buffer solutions as containing "weak acid + conjugate base" using chemical recipe cards.	Explain how a buffer resists pH change upon adding H+ or OH- using neutralization reaction frames.	Explain buffer action at the particulate level, writing net ionic equations for buffer component reactions with added strong acids/bases.
LT9	Calculate buffer pH using the Henderson-Hasselbalch equation template: pH = pKa + log([A-] / [HA]).	Calculate buffer pH and prepare buffers of specific pH using guided Henderson-Hasselbalch worksheets.	Calculate buffer pH before and after adding strong acid/base titrants, combining stoichiometry and Henderson-Hasselbalch calculations.
LT10	Select the buffer with highest capacity (highest concentration of components) using visual concentration cards.	Explain buffer capacity differences using comparative sentence frames (*"Buffer A has higher capacity because..."*).	Evaluate buffer capacity and optimal buffer range (pH = pKa +/- 1), designing buffers for target pH values.
LT11	Identify salts containing basic anions (e.g., F-, CO3^2-) whose solubility increases in acid using a visual rule card.	Explain how adding acid increases salt solubility by removing basic anions using Le Châtelier sentence starters.	Predict and mathematically/conceptually justify how changing pH affects salt solubility using coupled equilibrium equations.

Unit Overview

In Unit 8, students will apply the explanations and calculations they learned in Unit 7 to the acid-base equilibrium system. Students will collect titration data and develop titration curves to represent a variety of acid-base systems. They will analyze these titration curves to describe the similarities and differences between a strong acid-strong base and a weak acid-strong base or weak base-strong acid titration, identify the equivalence points and the half-equivalence points, and identify the buffering regions of the curves. Students will use the information presented graphically in the titration curves to complete calculations to find the equilibrium constant for the reactions (Ka or Kb), determine the concentration of an unknown, and support claims about how a particular buffer system may work when an acid or base is introduced. From these calculations and what is known about the chemical system, students will then develop explanations for how potential sources of error may have affected experimental results and associated calculations.

Lesson	Learning Target	Success Criteria	Suggested Activities
8.1 Introduction to Acids and Bases	**Learning Target 1** I can calculate pH and pOH using hydronium and hydroxide ion concentrations.	• I can use pH = -log[H3O+] and pOH = -log[OH-] to determine acidity or basicity. • I can relate hydronium and hydroxide ion concentrations using Kw. • I can explain that at 25°C, Kw = 1.0 × 10^-14 and pH + pOH = 14. • I can describe how pure water is neutral at 25°C but may not be neutral at other temperatures.	

8.2 pH and pOH of Strong Acids and Bases	**Learning Target 2** I can calculate pH and pOH for strong acid and strong base solutions.	• I can determine hydronium ion concentration from the initial concentration of a strong acid. • I can determine hydroxide ion concentration from the initial concentration of a strong base. • I can use the fact that strong acids and bases fully dissociate in water. • I can calculate pH and pOH from ion concentrations using logarithmic relationships.	**Post-Lab Discussion** Rainbow Acid Indicator (Flinn Scientific Item U0012) is added to 0.001 M solutions of HCl, H_2SO_4, and $HC_2H_3O_2$. Have students reason out why the pH values are not the same, concept of Ka. Then have them calculate the pH of each solution to explain their earlier observations. Percent ionization is discussed and how ICE charts reflect the percent ionization is explained.
8.3 Weak Acid and Base Equilibria	**Learning Target 3** I can explain how pH, pOH, and species concentrations are related in weak acid and weak base solutions.	• I can describe that weak acids and weak bases only partially ionize in water and establish equilibrium with their conjugates. • I can explain that pH of a weak acid depends on initial concentration and Ka (or pKa), and weak base pH depends on initial concentration and Kb (or pKb). • I can relate Ka and Kb through Kw for conjugate acid-base pairs. • I can calculate percent ionization of weak acids or bases using equilibrium and initial concentration values.	**Post-Lab Discussion** (See 8.2)
8.4 Acid-Base Reactions and Buffers	**Learning Target 4** I can explain how major species concentrations change when strong acids and strong bases are mixed, resulting in complete neutralization and determining pH from excess reactant.	• I can describe how mixing a weak acid with a strong base can produce a buffer, where pH depends on the relative amounts of the weak acid and its conjugate base. • I can explain how mixing a weak base with a strong acid can also produce a buffer, where pH depends on the ratio of the weak base and its conjugate acid. • I can determine pH in acid–base mixtures based on whether one reactant is in excess, equimolar, or forms a buffer system. • I can explain that when weak acids and weak bases are mixed, the system reaches equilibrium with both conjugate acid–base pairs present.	
8.5 Acid-Base Titrations	**Learning Target 5** I can explain how titration curves represent pH changes as a titrant is added to a mono- or polyprotic acid or base solution.	• I can determine the concentration of an unknown solution using the equivalence point where moles of acid and base are equal. • I can explain that at the half-equivalence point of a weak acid or base titration, the pH equals the pKa of the conjugate acid-base pair. • I can describe how the pH at the equivalence point depends on	**Post-Lab Discussion** After collecting data on a weak acid/strong base titration, have students create a titration curve (pH as a function of the volume of base added). Then have them identify relative points on the graph based on group discussion (e.g., equivalence point).

		the strength of the acid or base and the properties of the conjugate species formed. • I can use titration curves to identify the number of acidic protons in a polyprotic acid and determine corresponding pKa values.	
8.6 Molecular Structure of Acids and Bases	**Learning Target 6** I can explain how the strength of an acid or base is related to its molecular or ionic structure.	• I can identify which protons in a molecule are likely to participate in acid–base reactions based on structure. • I can explain that strong acids have weak conjugate bases that are stabilized by electronegativity, resonance, or inductive effects. • I can describe how structural features such as electronegative atoms increase acid strength by stabilizing the conjugate base. • I can compare strong and weak acids and bases by relating their strength to the stability of their conjugate partners.	
8.7 pH & pKa	**Learning Target 7** I can explain how the dominant form of a weak acid or base in solution depends on the relationship between pH and pKa (or pKb).	• I can predict whether the protonated or deprotonated form is more abundant by comparing pH to pKa. • I can explain that when pH is less than pKa, the protonated (acid) form is predominant, and when pH is greater than pKa, the deprotonated (base) form is predominant. • I can describe how acid–base indicators change color based on shifts between protonated and deprotonated forms. • I can explain why appropriate indicators are chosen in titrations based on matching their pKa to the equivalence point pH.	
8.8 Properties of Buffers	**Learning Target 8** I can explain how buffers stabilize pH by containing significant amounts of a conjugate acid-base pair.	• I can describe how the conjugate base in a buffer reacts with added acid to minimize pH change. • I can describe how the conjugate acid in a buffer reacts with added base to minimize pH change. • I can explain that buffer effectiveness depends on the ability of both components to neutralize added acid or base. • I can connect buffer action to the equilibrium between a weak acid and its conjugate base.	**Demo with Q&A** Add an Alka-Seltzer tablet to 200 mL of water and pour the resulting solution into three small beakers. Add deionized water to three more beakers. Add universal indicator to all six beakers and then add strong acids and strong bases to each beaker to demonstrate buffering ability and buffer capacity. Have students develop particulate-level drawings to illustrate what is happening in the beakers in the context of “buffering ability.”
8.9 Henderson-Hasselbalch Equation	**Learning Target 9** I can identify the pH of a buffer solution using the pKa of the weak acid and the ratio of conjugate base to weak acid concentrations.	• I can explain that buffer pH depends on the equilibrium between a weak acid and its conjugate base. • I can describe that adding small amounts of acid or base does not significantly change the ratio of conjugate pairs, so pH changes very little. • I can explain that buffers resist pH change because added acid or base is consumed by the conjugate pair. • I can relate buffer pH to the relative amounts of acid and base in the buffer system.	**Simulations** Using a Chem Collective virtual lab, ask students to develop a buffer that will have a particular pH after an amount of strong acid is added.

8.10 Buffer Capacity	**Learning Target 10** I can explain how buffer capacity depends on the total concentrations of the conjugate acid and conjugate base.	• I can explain that increasing the concentrations of both buffer components increases buffer capacity without changing pH if the ratio stays the same. • I can describe that buffer capacity is the ability of a buffer to resist changes in pH when acid or base is added. • I can explain that a buffer with more conjugate acid than base resists added base more effectively than added acid. • I can explain that a buffer with more conjugate base than acid resists added acid more effectively than added base.	**Simulations** (See 8.9)
8.11 pH and Solubility	**Learning Target 11** I can explain how changes in pH can affect the solubility of certain salts.	• I can identify that salts containing ions that act as weak acids, weak bases, or hydroxide ions are pH sensitive. • I can describe how adding acid or base can shift equilibrium and change solubility. • I can predict whether solubility increases or decreases based on the type of ion present. • I can relate pH changes to shifts in dissolution equilibrium.	

Progress Check 3

- Multiple-choice: ~30 questions
- Free-response: 1 question
    - Long

Preparing for the AP Exam

On the AP Exam, students must be able to use experimental data to make calculations and support claims. Students often encounter difficulty with questions that require them to use titration curves to identify the equivalence and half-equivalence points or to complete calculations or estimations of either the concentration or pH of an unknown at a particular point on the curve. They also struggle to justify the selection of an appropriate indicator for the end point of the titration. In these situations, students can face challenges with unit conversion, or they can confuse half-equivalence, equivalence, and endpoint. Students may also struggle to understand what is represented in different types of titration curves. Teachers can provide students with multiple opportunities to describe why titration curves have characteristic shapes for certain acid-base equilibrium systems. Teachers can also provide opportunities to choose and implement mathematical routines to manipulate and interpret titration data and connect that interpretation to chemistry concepts. The half-equivalence point is a helpful reference point to visualize ratios of acid/conjugate base, particularly when combined with particulate representations.

Unit Title:

Unit 9: Thermodynamics and Electrochemistry

Relevant Standards: Bold indicates priority

9.1 Introduction to Entropy: Students can use particulate-level models to explain entropy as the number of possible arrangements of particles and energy within a system.

9.2 Absolute Entropy and Entropy Change: Students can calculate and predict entropy changes for chemical and physical processes using thermodynamic data and mathematical relationships.

9.3 Gibbs Free Energy and Thermodynamic Favorability: Students can explain how enthalpy, entropy, and temperature determine whether a process is thermodynamically favorable.

9.4 Thermodynamic and Kinetic Control: Students can distinguish between thermodynamic favorability and reaction rate by connecting particulate-level processes to macroscopic observations.

9.5 Free Energy and Equilibrium: Students can use thermodynamic principles and mathematical relationships to explain the connection between Gibbs free energy and equilibrium.

9.6 Free Energy of Dissolution: Students can explain how intermolecular interactions and entropy changes affect the favorability of dissolution processes.

9.7 Coupled Reactions: Students can explain how energy released from one process can drive another process that is not thermodynamically favorable.

9.8 Galvanic (Voltaic) and Electrolytic Cells: Students can analyze electrochemical cells and predict how modifications to cell conditions or procedures affect cell behavior and experimental outcomes.

9.9 Cell Potential and Free Energy: Students can calculate relationships among cell potential, free energy, and spontaneity using electrochemical data.

9.10 Cell Potential Under Nonstandard Conditions: Students can justify how concentration and nonstandard conditions affect cell potential using chemical principles and mathematical reasoning.

9.11 Electrolysis and Faraday's Law: Students can apply Faraday's Law and electrochemical relationships to calculate quantities involved in electrolysis processes.

Essential Question(s):	**Enduring Understanding(s):**
1. Why do some chemical reactions occur without intervention, but others require the input of energy? 2. How can we determine the conditions under which a chemical or physical transformation is likely to occur? 3. How is electrical energy generated using chemical reactions?	1. The spontaneity of a chemical or physical process depends on the balance between energy changes and entropy changes within a system and its surroundings. 2. Gibbs free energy provides a quantitative way to predict whether a process is thermodynamically favorable under specific conditions. 3. Chemical reactions can transfer energy in the form of electrical work through the movement of electrons in redox reactions. 4. Electrochemical cells use oxidation–reduction reactions to convert chemical energy into electrical energy or use electrical energy to drive nonspontaneous reactions. 5. The direction and favorability of redox processes depend on factors such as cell potential, concentration, and thermodynamic conditions.
Demonstration of Learning:	**Pacing for Unit**
• Success with unit MCQs and FRQs via AP Classroom • Quizzes (AP Classroom MCQs and FRQs) every few topics	10 instructional days 2 lab days 2 days review / assess

• Practice with entropy, enthalpy, and Gibb's free energy calculations • What's the Driving Force Lab • Building a Galvanic Cell worksheet • Practice with cell potential calculations at standard and nonstandard conditions • Practice with Nernst calculations and responses to FRQs • Progress Check 9 from AP Classroom Unit 9 is 7-9% of AP Exam Weighting See AP Exam Description	
Family Overview (link below)	**Integration of Technology:**
AP Chemistry FAMILY MATERIALS	N/A
Unit-specific Vocabulary:	**Aligned Unit Materials, Resources, and Technology (beyond core resources):**

Entropy, Gibbs free energy, microstates, arrangements, positional possibilities, oxidation, reduction, redox reaction, oxidation number, half-reaction, electrochemical cell, galvanic cell, voltaic cell, anode, cathode, electrode, salt bridge, electrolyte, standard reduction potential, cell potential (Ecell), Nernst equation, spontaneous reaction, thermodynamically favorable, nonspontaneous reaction, thermodynamically unfavorable, Faraday's constant, electrolysis, concentration cell, fuel cell, standard hydrogen electrode (SHE)	• Multimeters to build galvanic cells
	  ○ Zinc and copper electrodes
	  ○ Batteries
	• Steel wool

Opportunities for Interdisciplinary Connections:	**Anticipated misconceptions:**
• Physics: entropy, spontaneity, and free energy • Biology: ATP and biochemical energy transformations • Environmental Science: energy efficiency and sustainability • Engineering: fuel cells, batteries, and energy systems • Earth Science: natural energy flow and geochemical processes	• Confusing enthalpy and entropy • Insufficient or inappropriate language to answer Unit 9 FRQs ○ disorder vs microstates, spontaneous vs thermodynamically favorable • Not considering the order of importance for determining change in entropy (change in moles of gas is more important than change in state) and explanation as to why • Assuming no appreciable reaction means it is at equilibrium or will not occur (vs under kinetic control) • Not changing the sign of the oxidized half reaction • Difficulty identifying parts of a galvanic cell • Not considering standard vs nonstandard conditions when calculating cell potential.
Connections to Prior Units:	**Connections to Future Units:**
• Students must know how to identify the oxidation number of all species within a reaction and write out oxidation / reduction half reactions (4.9) • Students must be able to calculate enthalpy using the 4 methods introduced in unit 6 • Students must be able to calculate the reaction quotient and equilibrium constant and determine the direction of reaction based on the magnitude (unit 7) • Students must be able to use dimensional analysis and stoichiometry to calculate change in mass of electrode when a current is applied (pre-work and Unit 4)	N/A
Differentiation through *Universal Design for Learning*	

	Engagement	Representation	Action & Expression
LT1	"Microstate Sorting Game" arranging gas particles across connected flasks to observe probability of distribution/disorder (ΔS).	Conceptual matrix mapping entropy increases (ΔS > 0) to phase changes (s -> l -> g), temperature increases, and gas mole generation.	Predict the sign of ΔS° for physical phase changes and chemical reactions, justifying answers with structural molecular reasoning.
LT2	Molar entropy calculation challenge computing ΔS°_rxn for synthesis vs. decomposition reactions.	Standard entropy formula scaffold: ΔS°_rxn = sum(n × S°(products)) - sum(m × S°(reactants)) (noting S° > 0 for elements).	Calculate ΔS°_rxn from standard molar entropy tables and confirm that the algebraic sign matches structural predictions.
LT3	Gibbs free energy decision lab evaluating temperature dependent spontaneity for ice melting vs. combustion.	ΔG° = ΔH° - TΔS° sign matrix detailing thermodynamic favorability conditions (ΔG° < 0 -> Favored).	Calculate ΔG° using enthalpy and entropy values and state whether a reaction is thermodynamically favored at given temperatures.
LT4	"Thermodynamic vs. Kinetic Control Debate" analyzing why diamond conversion to graphite (ΔG° < 0) does not occur perceptibly.	Energy profile diagram contrasting a large negative ΔG° (thermodynamically favored) with a high activation energy E_a barrier (kinetic control).	Write a CER response explaining why a thermodynamically favored reaction may require a catalyst or high heat to proceed at a measurable rate.
LT5	Mathematical modeling of ΔG° = -RT ln(K) observing how equilibrium constants scale exponentially with free energy changes.	Dual-axis conversion chart connecting ΔG° < 0 <-> K > 1 (product favored) and ΔG° > 0 <-> K < 1 (reactant favored).	Calculate K from ΔG° values using ΔG° = -RT ln(K) and explain the thermodynamic favorability of the system.
LT6	Dissolution enthalpy/entropy audit evaluating why endothermic dissolution processes (e.g., NH4NO3) occur spontaneously due to +ΔS.	Dissolution thermodynamic balance diagram illustrating solute/solvent lattice breaking (ΔH > 0) vs. hydration entropy gain (ΔS > 0).	Write an explanation detailing how the balance between ΔH_soln and ΔS_soln determines salt solubility across temperatures.
LT7	Electrolysis demonstration using an external power source to drive water splitting (ΔG° > 0) into H2 and O2.	Reaction coupling schematic showing an unfavorable process (ΔG1° > 0) coupled to a favorable process or external current (ΔG_overall° < 0).	Design a coupled reaction scheme or explain how electrolysis uses electrical energy to drive a non-spontaneous reaction.
LT8	Construction lab building a Galvanic cell (Cu/Zn) using beakers, wire, voltmeter, and a salt bridge.	Diagram of a galvanic cell labeling Anode (oxidation, -), Cathode (reduction, +), electron flow (A -> C), and ion movement in the salt bridge.	Construct a functional galvanic cell, draw a fully labeled diagram, and write net ionic equations and electron/ion flow directions.
LT9	Standard reduction potential table activity calculating E°_cell = E°_cat - E°_an for various metal electrode combinations.	Formula connection visual linking E°_cell > 0 <-> ΔG° < 0 via ΔG° = -nFE°_cell (where F = 96,485 C/mol e-).	Calculate E°_cell and ΔG° for electrochemical cells and determine whether cell reactions are thermodynamically favored.
LT10	Non-standard voltaic cell lab measuring voltage shifts as ion concentrations in anode/cathode compartments change.	Nernst equation visual scaffold [E_cell = E°_cell - (RT / nF) ln(Q)] linking Q < 1 -> E_cell > E°_cell and Q > 1 -> E_cell < E°_cell.	Predict how altering reactant/product concentrations shifts Q and cell potential E_cell away from standard potential E°_cell.
LT11	Electroplating lab electroplating copper onto a nickel coin using a constant current power supply.	Stoichiometric electrochemistry bridge: Current (I = q / t) -> Charge (q) -> Moles of e- -> Moles/Grams of Metal.	Solve stoichiometry problems for electrolysis and electroplating using I = q / t and Faraday's constant (F = 96,485 C/mol e-).

Supporting Multilingual/English Learners (*CELP standards*)

	Emerging	Expanding	Bridging
LT1			
LT2			
LT3			
LT4			
LT5			

Unit Overview

To achieve success in AP Chemistry and in Unit 9 specifically ,students must connect principles and calculations across the areas of kinetics, thermodynamics, equilibrium, and electrochemistry to explain and support claims about

what is happening in chemical systems. Sometimes support of such claims comes from students being able to estimate an approximate value of a required characteristic of a chemical system rather than use a routine application of an algorithm. Students are introduced to entropy as a factor that is necessary to explain why some endothermic reactions occur in spite of the higher energy that products may have in these changes. Students will use particulate representations and graphical distribution of kinetic energy to describe the increase in entropy with increasing temperature. In addition, students will explore how to use Gibbs free energy for determining the thermodynamic favorability by considering the change in both enthalpy and entropy. Students will use the concepts of thermodynamics to generate more comprehensive claims about what is happening in a galvanic or electrolytic cell.

Lesson	Learning Target	Success Criteria	Suggested Activities
9.1 Introduction to Entropy	**Learning Target 1** I can identify whether entropy increases or decreases during chemical and physical processes.	• I can explain that entropy increases when matter becomes more dispersed, such as during phase changes from solid to liquid or liquid to gas. • I can describe how entropy increases when gases expand or when the number of gas particles increases in a reaction. • I can explain that entropy increases with temperature because energy becomes more dispersed among particles. • I can compare relative entropy changes based on changes in phase, volume, number of gas particles, and temperature.	
9.2 Absolute Entropy and Entropy Change	**Learning Target 2** I can calculate the standard entropy change for a reaction using standard molar entropy values.	• I can determine entropy change by subtracting the total entropy of reactants from the total entropy of products. • I can apply tabulated entropy data to chemical and physical processes. • I can predict whether entropy increases or decreases based on calculated values. • I can use entropy values to analyze disorder changes in a system.	
9.3 Gibbs Free Energy and Thermodynamic Favorability	**Learning Target 3** I can explain whether a process is thermodynamically favored based on the sign of Gibbs free energy change (ΔG°).	• I can determine that a process is thermodynamically favored when ΔG° is less than zero. • I can calculate ΔG° using standard Gibbs free energy of formation values for reactants and products. • I can calculate ΔG° using the relationship between enthalpy, entropy, and temperature. • I can predict thermodynamic favorability by analyzing the signs of ΔH°, ΔS°, and temperature without full calculation.	**Think-Pair-Share** Given a problem pertaining to thermodynamic favorability, have students think through how enthalpy and/or entropy is driving the thermodynamic favorability of the reaction. Have them pair up and explain their reasoning for whether or not the reaction is thermodynamically favorable and what is driving that favorability. After the pairs have discussed their responses, have them share with other pairs to get feedback on their rationale.
9.4 Thermodynamic and Kinetic Control	**Learning Target 4** I can explain that a thermodynamically favored reaction may still not occur at a measurable rate due to kinetic barriers.	• I can describe that high activation energy can prevent a reaction from proceeding quickly even if it is thermodynamically favorable. • I can explain that such reactions are said to be under kinetic control. • I can distinguish between thermodynamic favorability and reaction rate. • I can explain that a lack of observable reaction does not necessarily mean the system is at equilibrium.	
9.5 Free Energy and Equilibrium	**Learning Target 5** I can explain whether a process is thermodynamically favored using the	• I can describe that a process is thermodynamically favored when ΔG° is less than zero and K is greater than 1. • I can relate ΔG° and K using the equations $\Delta G^\circ = -RT \ln K$ and $K = e^{\wedge}(-\Delta G^\circ/RT)$. • I can explain that when ΔG° is close to zero, K is close to 1 and neither reactants nor products are strongly favored.	

	relationship between ΔG°, K, and temperature.	• I can predict whether reactants or products are favored by comparing the sign and magnitude of ΔG° relative to RT.	
9.6 Free Energy of Dissolution	**Learning Target 6** I can explain how the solubility of a salt depends on changes in enthalpy and entropy during dissolution.	• I can describe how breaking the ionic lattice and forming solute–solvent interactions affects the enthalpy change of dissolution. • I can explain how increased disorder from dissolved ions contributes to the entropy change. • I can describe how solvation of ions by water molecules influences both enthalpy and entropy. • I can explain that solubility depends on the overall free energy change, which results from a balance of enthalpy and entropy effects.	
9.7 Coupled Reactions	**Learning Target 7** I can explain how external energy sources can drive thermodynamically unfavorable processes.	• I can describe how electrical energy can be used to force nonspontaneous reactions in electrolysis or battery charging. • I can explain how light energy can drive unfavorable reactions such as photosynthesis. • I can describe how coupling a thermodynamically unfavorable reaction with a favorable one can make the overall process favorable. • I can explain that coupled reactions share intermediates and result in an overall process with negative ΔG°.	
9.8 Galvanic (Voltaic) and Electrolytic Cells	**Learning Target 8** I can explain how each component of an electrochemical cell contributes to the overall operation of the cell.	• I can describe how electrodes, solutions, and the salt bridge work together to allow electron and ion flow. • I can explain the difference between galvanic and electrolytic cells in terms of thermodynamic favorability and energy input. • I can identify that oxidation occurs at the anode and reduction occurs at the cathode in all electrochemical cells. • I can relate macroscopic observations (voltage, mass changes, gas formation) to particle-level electron transfer in half-reactions.	**Demo with Q&A** Construct a simple battery by submerging two electrodes (Mg and Cu) into orange juice and attaching it to the battery compartment of a quartz clock. Instruct students to ask as many questions as they can while the clock is running. Allow the clock to run for as long as possible and then examine the magnesium anode after a day to see if it corrodes away. As a class, examine the table of standard reduction potentials and discuss where the electrons are coming from and going to in order to power the clock.
9.9 Cell Potential and Free Energy	**Learning Target 9** I can explain whether an electrochemical cell is thermodynamically favored based on the sign of its standard cell potential.	• I can determine that a cell is thermodynamically favored when the standard cell potential (E°_{cell}) is positive. • I can explain that a negative E°_{cell} indicates a thermodynamically unfavored reaction that requires external energy. • I can identify oxidation and reduction half-reactions using standard reduction potentials to calculate E°_{cell}. • I can relate cell potential to Gibbs free energy using $\Delta G^\circ = -nFE^\circ$, where positive cell potential corresponds to negative ΔG°.	
9.10 Cell Potential Under Nonstandard Conditions	**Learning Target 10** I can explain how changes in concentration from standard conditions affect cell potential.	• I can describe that cell potential depends on how far a system is from equilibrium. • I can explain that cell potential is zero at equilibrium and decreases in magnitude as equilibrium is approached. • I can describe that deviations from standard conditions can increase or decrease cell potential depending on how they shift the system relative to equilibrium.	

		• I can determine the direction of spontaneous electron flow based on the system's tendency to reach equilibrium. • I can explain how nonstandard concentrations affect the cell potential of an electrochemical cell. • I can describe that cell potential decreases as a system approaches equilibrium. • I can use the Nernst equation conceptually to relate cell potential to reaction conditions. • I can explain that increasing Q lowers the cell potential, while decreasing Q increases it. • I can predict qualitative changes in cell potential without relying solely on calculations.	
9.11 Electrolysis and Faraday's Law	**Learning Target 11** I can calculate the amount of charge transferred in an electrochemical cell using changes in reactants and products.	• I can relate the number of electrons transferred in a redox reaction to the amount of substance produced or consumed. • I can use Faraday's laws to connect current, time, and charge in electrochemical processes. • I can apply the relationship I = q/t to determine current or charge in a system. • I can use stoichiometry to connect ionic charge, electron transfer, and mass changes at electrodes.	**Critique Reasoning** Have students mass a new penny with an analytical balance. They attach the penny to the negative electrode, which is attached to a 9-volt battery. A zinc strip is attached to the positive electrode. The penny is submerged for 10 minutes in a 1.0M NaOH solution with zinc dust and the zinc electrode. Students dry the penny and mass it again. Using Faraday's laws, have them calculate the current that must have been delivered to plate the zinc on to the penny. Then have student pairs share and peer review each other's reasoning.

Progress Check 9

- Multiple-choice: ~30 questions
- Free-response: 2 questions
    - Short
    - Long

Preparing for the AP Exam

On the AP Exam, students must be able to provide an appropriate explanation of the connection between entropy, enthalpy, and Gibbs free energy and the thermodynamic favorability of a chemical reaction. Students often struggle with questions that require them to reason about whether enthalpy, entropy, or both drive a reaction. They will state that both enthalpy and entropy drive the reaction by using the equation for Gibbs free energy instead of reasoning about which might be more of a driving factor than the other. Further, some students fail to connect macroscopic observational data to the concepts of entropy and enthalpy to support claims about which concept was driving the reaction. Teachers can ensure that students understand that the first step in making thermodynamic favorability predictions is to define and interrelate enthalpy, entropy, and Gibbs free energy in relation to driving chemical or physical processes. Students should be shown how the concepts of kinetics, equilibrium, and thermodynamics are connected in order to explain why thermodynamically favorable reactions might produce small concentrations of product and why unfavorable reactions can produce large concentrations of product.

AP Exam Description

The AP Chemistry Exam assesses student application of the science practices and understanding of the learning objectives outlined in the course framework. The exam is 3 hours and 15 minutes long and includes 60 multiple-choice questions (MCQ) and 7 free-response questions (FRQ). A scientific or graphing calculator is recommended for use on both sections of the exam. Students are provided with the periodic table and a formula sheet that lists specific and relevant formulas for use on the exam (see CED Appendixes). The details of the exam, including exam weighting and timing, can be found below:

Section	Question Type	Number of Questions	Exam Weighting	Timing
I	**Multiple-choice questions**	**60**	**50%**	**90 minutes**
II	**Free-response questions**		**50%**	**105 minutes**
	Long questions (10 points each)	3		
	Short questions (4 points each)	4		

Units of Instruction	Exam Weighting
Unit 1: Atomic Structure and Properties	**7–9%**
Unit 2: Compound Structure and Properties	**7–9%**
Unit 3: Properties of Substances and Mixtures	**18–22%**
Unit 4: Chemical Reactions	**7–9%**
Unit 5: Kinetics	**7–9%**
Unit 6: Thermochemistry	**7–9%**
Unit 7: Principles of Equilibrium	**7–9%**
Unit 8: Acids and Bases	**11–15%**
Unit 9: Thermodynamics and Electrochemistry	**7–9%**

Section I: Multiple-Choice (MCQ)

Science Practices 1, 2, 4, 5, and 6 are all assessed in the multiple-choice section with the following exam weighting (Science Practice 3 is not assessed in the multiple-choice section):

Science Practice	Exam Weighting
Practice 1: Models and Representations	**8–12%**
Practice 2: Question and Method	**8–12%**
Practice 4: Model Analysis	**23–30%**
Practice 5: Mathematical Routines	**35–42%**
Practice 6: Argumentation	**8–12%**

Section II: Free-Response (FRQ)

All six science practices are assessed in the free-response section with the following exam weighting:

Science Practice	Exam Weighting
Practice 1: Models and Representations	**2–4%**
Practice 2: Question and Method	**10–16%**
Practice 3: Representing Data and Phenomena	**8–16%**
Practice 4: Model Analysis	**5–9%**
Practice 5: Mathematical Routines	**43–53%**
Practice 6: Argumentation	**15–24%**