<u>Pathology Informatics Curriculum Template and Self-Study Guide</u>
<u>MMM-DD-2025</u>

The template described below provides a framework as an introduction and self-study guide for Veterinary Pathology trainees, affiliate members and diplomates to learn more about informatics. Resources for each key area are provided. Pathology Informatics Essentials for Residents (PIER) resources (https://www.apcprods.org/pier), developed by the Association of Pathology Chairs, Association for Pathology Informatics, and College of American Pathologists, were adapted to our needs.

The template was based on an estimate of 72 hours (= 9 days) of informatics content during a 3-year training period. However, the materials can be adapted or expanded according to the available resources at the training program and/or the learner's career interest. Please note, consultation with non-pathology experts in computational analysis is encouraged within a university setting or by reaching out to other experts in the field. Moreover, we should recognize that pathology informatics is an evolving field and that this content should be evaluated and updated, as appropriate, annually.

Estimated time for each topic:

Topic	**Weightage (%)**	**No. of hours**
Computing Fundamentals	12	8
Importance of Databases	12	8
Medical Informatics Standards	12	8
Molecular Pathology Fundamentals	12	8
Digital Pathology	25	20
Image Analysis	15	12
Artificial Intelligence	12	8
Total	100%	72 hours (9 days)

Topic 1:	**Computing Fundamentals**
Rationale	Computers and data mining/analysis are essential tools that veterinary pathologists use in the management of information for laboratory practice, diagnostics, and patient care.
Expected results	Understand and use correct terminology to describe the major types and components of computer hardware, software, and computer networks.
Subtopics, beginner	• Recognize the significance of informatics in pathology practice. • Understand the role of Laboratory Information Systems (LIS) in effective laboratory operations and health care delivery. • Understand principles of privacy, data integrity, computer system password protection, authentication, restriction of social media use, cookies, viruses, ransomware that can affect LIS systems.
Subtopics, expert	Expert: Know biases and limitations of LIS systems.
Recommended Resources	Pantanowitz L, Tuthill JM, Balis UGJ, eds. Pathology Informatics: Theory and Practice. Chicago, IL: ASCP Press; 2012 Pages 1-8. Pathology informatics: an introduction Pages 67-84. Networking Pantanowitz L, Parwani AV, eds. Practical informatics for cytopathology. Springer Science+Business Media New York 2014 Pages 5-14. Basic Computing Pages 47-60. Laboratory Information Systems Pages 61-70. Laboratory Information System Operations and Regulations Pages 185-193. Appendix A: Key Definitions Bunch DR, Holmes DT. Clinical Pathology and the Data Science revolution. J Mass Spectrom Adv Clin Lab. 2022 Mar 17;24:41-42. doi: 10.1016/j.jmsacl.2022.03.001. PMID: 35340694; PMCID: PMC8942826
Practical Exercises	• List and explain disciplines of pathology informatics. • Identify your specific computer setup hardware components. • Describe your site's specific LIS system capabilities and constraints. • Describe your group's rules for privacy, data integrity, computer system password protection, authentication, restriction of social media use, cookies, viruses, ransomware that can affect LIS systems.
Link to Additional Resources	Computing Fundamentals

Topic 2:	**Importance of Databases**
Rationale	Databases provide the core structure and tools that enable pathologists to manage and analyze large amounts of information.
Expected results	Conversant in the fundamentals of databases: Data types, fields, records, database structure, and mechanisms for querying data. Understands how data storage affects data retrieval options.
Subtopics, beginner	• Understand basics of database applications terminology of coding (FileMaker, spreadsheet software, programming languages e.g. R, Python). • Structured versus unstructured data. • Character limits within LIS fields. • Types and uses of databases. • Understand how database structure affects data queries & retrieval. • Familiarity with Excel, R and data visualization such as SAS, Tableau, and Power BI.
Subtopics, expert	• Utilize or develop a structured input for conditions within your LIS. • Demonstrate using a database for visualization applications (build a chart). • Familiarity with Structured Query Language (SQL) and interrelational databases.
Recommended Resources	• https://www.pathologyoutlines.com/topic/informaticsdatabasefundamentals.html
Practical Exercises	• Perform an open text search "Natural Language Search" (text/keyword search) in the Laboratory Information System (LIS) (if available) to identify a number of cases with a particular diagnosis. Discuss "false positives" and the reasons for them occurring in the match list (for example, matched a word in the note or matched a negated diagnosis. Example: getting myxoma when searching for myxomatous). • Demonstrate the ability to use a database application (e.g., Shiny from R Studios, FileMaker, MS-Excel, MS-Access) to design and build a simple database for a particular purpose (such as a QA project, an address book) condition category frequency). Know how to save files as .csv .xlxs for export. • Learn examples of data analysis tools and their use in statistics and visualization (e.g., eg, Shiny, ggplot2, dyplr from R-Studio, pandas, numpy, matplotlib in Python).
Link to Additional Resources	Importance of Databases

Topic 3:	**Medical Informatics Standards**
Rationale	Standards enable sharing of data among health care information systems (i.e. interoperability), which is necessary for patient care.
Expected results	• Understand the basics of the standards development process. • Define the key features of communication standards used in pathology, such as National Animal Health Laboratory Network (NAHLN) and Health Level 7 (HL7). • Familiarity with standard terminology systems: SNOWMED CT, LOINC, SEND, INHAND. • Recognize the advantages and disadvantages of standardized terminology for creating interchangeable data that can be retrieved and summarized.
Subtopics, beginner	• Understand the characteristics and appropriate applications of standard terminologies: • International Standards Organization (ISO), Integrating the Healthcare Enterprise (IHE), Office of the National Coordinator (ONC)] [e.g. Systematized Nomenclature of Medicine Clinical Terms (SNOMED CT), and Logical Observation Identifiers Names and Codes (LOINC)] used to represent pathology data in the LIS and Electronic Health Record (EHR). • For rodents, describe the characteristics and appropriate applications of International Harmonization of Nomenclature and Diagnostic Criteria (INHAND), Standard For Exchange Of Nonclinical Data (SEND)].
Subtopics, expert	• Using available literature, practically make a synoptic report template that is repeatable with little interobserver variance that applies one of the systems above.
Recommended Resources	• Benson T. Principles of Health Interoperability; SNOMED CT, HL7 and FHIR (Health Information Techology Standards) 3rd. London, England: Springer-Verlag: 2016 Pages 21-31. Chapter 2: Why is interoperability hard? Pages 51-70. Chapter 4: Unified Modeling Language (UML) and Extensible Markup Language (XML) Pages 83-98. Chapter 6: Standards development organizations Pages 101-19. Chapter 7: HL7 & version 2.x Pages 201-79. Part III SNOMED and terminology • Pantanowitz L, Tuthill JM, Balis UGJ, eds. Pathology Informatics Theory & Practice. Chicago, IL: ASCP; 2012 Pages 179-86. Beckwith B. Coding Pages 135-40. Balis U. Information systems interfaces and interoperability
Practical Exercises	• Review browsing, lookup, and automatic coding using standard terminologies in the NCBO BioPortal: https://bioportal.bioontology.org/ • Compare and contrast the structure and concept content of SNOMED CT, ICD 10/11, VET ICD-O, LOINC, and CPT using the BioPortal browser displays for pathology reports. • Code a set of AP and CP pathology reports utilizing one of the above coding systems or your institution's preferred system that contain a range of procedure and clinical concepts, of varying complexity (e.g., at least one synoptic report should be included).
Link to Additional Resources	Medical Information Standards

Topic 4:	**Molecular Pathology Fundamentals**
Rationale	As advanced molecular technique-based tests are applicable to pathology samples, there is an increasing need for pathology trainees to receive a strong foundation in molecular pathology.
Expected results	Understand the principles and applications of basic and advanced molecular pathology tools in pathology practice.
Subtopics, beginner	• Understand terminologies and concepts used in molecular pathology, including PCR, NGS, bulk and single cell RNA sequencing (RNA-seq), copy number variations (CNV), single nucleotide polymorphisms (SNPs), spatial transcriptomics, Omics, MALDI-MS, CYTOF, and single cell analysis. • Understand the basic principles and components of tissue section based molecular pathology, including in situ hybridiation (ISH), immunohistochemistry (IHC), multiplexing, and immunofluorescence (IF) assays.
Subtopics, expert	• Design experiments including controls, validation and protocols. • Both readout and troubleshoot techniques such as IHC, IF or ISH for diagnostic or transgenic samples. • Be able to build a technique for a molecular application and quantify samples for research applications.
Recommended Resources	• https://www.pathologyoutlines.com/topic/molecularnextgensequencing.htm • pathologyoutlines.com/topic/stainsihcprocedure.html • Park J et al. 2022. Spatialomics technologies at multimodal and single cell/subcellular level. Genome Biology (23) • Coleman W and Tsongali G eds. Essential Concepts in Molecular Pathology. 2nd Ed. Pages 563-578. Molecular assessment of human diseases in the clinical laboratory • Netto GJ, Schrijver I eds. Genomic Applications in Pathology. 2nd ed. Springer New York Heidelberg Pages 33-49: Reuther J, Roy A, and Monzon FA. Transcriptome Sequencing (RNA-Seq) • Thurin M, Cesano A, and Marincola FM eds. Biomarkers for Immunotherapy of Cancer: Methods and protocols (Methods in Molecular Biology) 1st ed. 2020 Edition) Pages 455-465. Patel SS and Roding SJ. Overview of Tissue Imaging Methods
Practical Exercises	• Quantify regions of interest in IHC, FISH, or multiplex samples. • Order and interpret mutational analysis on suitable diagnostic cases. • Outline an experimental design and protocol for one of these techniques.
Link to Additional Resources	Molecular pathology fundamentals

Topic 5:	**Digital Pathology**
Rationale	Digital images and associated data analysis are essential tools that veterinary pathologists use for analysis in laboratory research and patient care. The use of these tools requires an understanding of how images are digitalized and manipulated.
Expected results	Understand the hardware and software components of a digital pathology workflow as well as the attributes and pitfalls of digitalization of images.
Subtopics, beginner	• Introduction to digital pathology: history, basics of digital imaging, digital microscopy, whole slide imaging (WSI), image representation, color representation and concepts of resolution. • Know that there are different requirements for different scanners. • Basic understanding of hardware (digital cameras, optics, scanners), software (image viewers, networking, integration of metadata), digital pathology-related guidelines and recommendations. • Introduction to specific software applications such as Q Path. • Digital slide workflow, including pre-imaging parameters, acquisition, storage and image management and visualization. • Understand the limitations of digital pathology (i.e. round cell tumor analysis, polarizing). • Understand content-based image retrieval (CBIR) and its significance.
Subtopics, expert	• Know the importance of standardized concept of differing image formats for standards for handling, storing, printing, and transmitting information in pathology imaging such as Digital Imaging and Communications in Medicine (DICOM). • Outline and discuss a validation scheme for bringing a new scanner into a lab for use in workflow.
Recommended Resources	• Aeffner F, Adissu HA, Boyle MC, et al. Digital Microscopy, Image Analysis, and Virtual Slide Repository. ILAR journal 2018, 59:66-79 • Bertram CA, et al. Validation of digital microscopy: Review of validation methods and sources of bias. Veterinary Pathology 2022, 59: 26-38 • Kim D, Sundling KE, Virk R, et al. Digital Cytology Part 1: Digital Cytology Implementation for Practice: A Concept Paper with Review and Recommendations from the American Society of Cytopathology Digital Cytology Task Force. Journal of the American Society of Cytopathology. 2023 Dec • Q Path: https://qupath.github.io/
Practical Exercises	• Perform whole slide imaging with an operator and save to an appropriate storage medium. • Open images from an image management system (IMS) view, annotate and diagnose a digital WSI slide. • Process map an entire digital pathology workflow with hardware and software. • Discuss what can adversely affect the digital imaging process and how to mitigate or rectify the process. • List the factors that impact image size or resolution. • Use digital slides (with or without annotations) for teaching students during their coursework.
Link to Additional Resources	Digital Pathology

Topic 6:	**Image Analysis**
Rationale	Pathologists are increasingly becoming responsible for including automated image analysis results in their assessments.
Expected results	Understand basics of image processing and analysis including components of an image analysis pipeline.
Subtopics, beginner	• Familiarity with software for pathology image analysis: freely available and open sourced (i.e. QuPath) and commercial software (e.g. Indica Labs HALO, Visiopharm, Omero+). • Understand the components of an image analysis pipeline: study design, pre-analytical variables, sample suitability, image pre-processing, annotation, algorithm selection, threshold setting, post-processing, data interpretation and reporting. • Understanding of some main applications of image analysis to digital pathology: area-based measurements, cell-based measurements, object-based measurements, Artificial Intelligence (AI) in digital pathology. • Understand the roles of the pathologist as a member of an image analysis team: quality control of tissue selection. - ID which pattern recognition should be used for tasks: which pattern recognition task should be used – classification, object detection, segmentation), workflow requirements, proper fixation, free of artifacts, clear detail. - Analysis: proper cell segmentation, correct anatomical localization of structures of interest. Post analysis: data interpretation, slide/specimen exclusion and final review.
Subtopics, expert	• Understand how to choose an appropriate algorithm for image analysis projects. • Awareness of hyperparameters (i.e. batch size, number of epochs for machine learning within the program, training and iterations) and how to set them when appropriate. • Understand "color" in the concept of brightfield vs fluorescence images. • Basic understanding of stereological principles.
Recommended Resources	• Aeffner et al. 2016. Commentary: Roles for Pathologists in a High-throughput Image Analysis Team. Toxicol Pathol. 44(6):825-34 • Brown (2017). Bias in image analysis and its solution: unbiased stereology. J Toxicol Pathol. 30(3):183-191 • Webster and Dunstan (2014). Whole-Slide Imaging and Automated Image Analysis: Considerations and Opportunities in the Practice of Pathology. Veterinary Pathology, 51(1), 211–223
Practical Exercises	• Select or create a basic algorithm to review basic principles such as tissue vs glass, stroma vs tissue, or nuclei vs cells via software i.e. QuPath or HALO. • Set the threshold for a positive/negative staining in immunohistochemistry assessment. • Annotate a set of slides for a specific finding (i.e. tumor, necrosis). • Assess algorithm markup of a feature segmentation, object pattern recognition, and other similar applications to identify if the features (i.e. nuclei) are identified properly. • Interpret an image analysis report. • Perform quality control the accuracy of an analysis algorithm.
Link to Additional Resources	Image Analysis

Topic 7:	**Artificial Intelligence (AI)**
Rationale	Recent advancements in machine learning (ML), deep learning (DL) and AI tools carry the potential to make significant contributions to health care, particularly in pathology.
Expected results	Demonstrate fundamental understanding and apply principles of AI in pathology practice.
Subtopics, beginner	• Understand basic definitions of artificial intelligence, machine learning (ML), neural network, deep learning (DL), convolutional neural networks (CNN), architecture, models, supervised vs unsupervised learning, weakly supervised learnings such as large language models (LLM). • Understand your institutional restrictions on sharing information with AI resources. • Understand hallucinations in AI. • Understand the ethical use of AI in research and scientific publication.
Subtopics, expert	• Acquaintance with machine learning applications/methods for efficient veterinary medical decision support. • Understand the concepts of using training, validation and test sets in AI experiments and how training can impact output. • Understand verification of data output.
Recommended Resources	• Lee P Goldberg C, and Kohane I with Sebastien Bubeck. 2023. The AI Revolution in Medicine: GPT-4 and Beyond, 1st edition. Pearson • McAlpine, E.D. and Michelow, P. (2020) The cytopathologist's role in developing and evaluating artificial intelligence in cytopathology practice. Cytopathology doi:10.1111/cyt.12799 • Tizhoosh and Pantanowitz (2018) Artificial Intelligence and Digital Pathology: Challenges and Opportunities. J Pathol Inform. 9:38 • Turner et al. (2020). Society of Toxicologic Pathology Digital Pathology and Image Analysis Special Interest Group Article: Opinion on the Application of Artificial Intelligence and Machine Learning to Digital Toxicologic Pathology. Toxicol Pathol. 48(2):277-294
Practical Exercises	• Utilize an AI system for Image Analysis (still and WSI applications) – examples utilizing QuPath or HALO to differentiate IHC or immunocytochemistry (ICC) uptake, removing stromal/epithelial elements, quantification or evaluation of cellular features, classification of tissue structures, identification of artifact or elimination of artifact. • Learn appropriate annotation for the AI application that you are utilizing. • Utilize AI for database analysis. • Describe input and output limitations of data for pathology. • Use an AI application such as a large language model to generate a didactic or synoptic pathology report for a patient and disease condition. • Explain the applications and limitations of numerical, image, and text-based AI technologies. • Explain the underlying biases of AI and nonsynthetic and synthetic data and how to limit them with appropriate data.
Link to Additional Resources	Artificial Intelligence (AI)

Additional Resources by Topic

Topic 1:	Computing Fundamentals
Additional resources	• Zuraw A, Digital Pathology 101. All you need to know to start and continue your digital pathology journey (https://amzn.to/3Q1dLNR). • *Journals:* • Carey MA, Papin JA. 2018. Ten simple rules for biologists learning to program. PLoS Comput Biol. 14(1):e1005871 • Ekmekci B, McAnany CE, Mura C. 2016. An Introduction to Programming for Bioscientists: A Python-Based Primer. PLoS Comput Biol. 12(6):e1004867 • Troth SP, Everds NE, Siska W, Knight B, Lamb M, Hutt J. 2018. Scientific and Regulatory Policy Committee Points to Consider: Data Visualization for Clinical and Anatomic Pathologists. Toxicol Pathol. 46(5):476-487 • Cucoranu IC, Parwani AV, West AJ, Romero-Lauro G, Nauman K, Carter AB, Balis UJ, Tuthill MJ, Pantanowitz L. 2013. Privacy and security of patient data in the pathology laboratory. J Pathol Inform. 14;4:4 • Albahra, Samer, et al. "Artificial intelligence and machine learning overview in pathology & laboratory medicine: A general review of data preprocessing and basic supervised concepts." Seminars in Diagnostic Pathology. Vol. 40. No. 2. WB Saunders, 2023 • Yang Y, Sun K, Gao Y, Wang K, Yu G. Preparing Data for Artificial Intelligence in Pathology with Clinical-Grade Performance. Diagnostics. 2023; 13(19):3115. https://doi.org/10.3390/diagnostics13193115 • Rashidi, Hooman H., et al. "Artificial intelligence and machine learning in pathology: the present landscape of supervised methods." Academic pathology 6 (2019): 2374289519873088 • Pantanowitz L, Tuthill JM, Balis UGJ, eds. Pathology Informatics: Theory and Practice. Chicago, IL: ASCP; 2012. Pages 11-33. Park S, Balis U, Pantanowitz L. Computer fundamentals. • Sinard JH, ed. Practical Pathology Informatics. New York, NY: Springer Science + Business Media, Inc.; 2006. Pages 83-120. Sinard JH. Networking and the Internet • Free R books: https://github.com/RomanTsegelskyi/rbooks#readme *Journals:* • Sinard JH, Powell SZ, Karcher DS. Pathology training in informatics: evolving to meet a growing need. Arch Pathol Lab Med. April 2014;138(4):505-11 • Clay MR, Fisher KE. Bioinformatics education in pathology training: current scope and future direction. Cancer Inform. 2017 Apr 10;16:1176935117703389 *Online resources:* • Tyson J, Crawford S. How PCs work. How Stuff Works Tech website (https://computer.howstuffworks.com/pc.htm) • Woodford C. Computer networks. Explain That Stuff website (https://www.explainthatstuff.com/howcomputernetworkswork.html) • The Python Tutorial: (https://docs.python.org/3/tutorial/index.html) • Veterinary Immunohistochemistry Database: https://www.ihcdatabase.com/ Please note, not all inclusive of all vendors

Topic 2:	Importance of Databases
Additional resources	• Pantanowitz L, Tuthill JM, Balis UGJ, eds. Pathology Informatics: Theory and Practice. Chicago, IL: ASCP; 2012. Pages 35-65. Park SL, Parwani AV, Pantanowitz L. Databases • Sinard JH, ed. Practical Pathology Informatics. New York, NY: Springer Science + Business Media, Inc.; 2006. Pages 121-172. Sinard JH. Databases • Cimino JJ: Desiderata for controlled medical vocabularies in the twenty-first century. Methods Inf Med 1998:37(4-5):394-403 *Online resources:* • Access, Database design basics, https://support.microsoft.com/en-us/office/database-design-basics-eb2159cf-1e30-401a-8084-bd4f9c9ca1f5 • Coursera and Linked in Courses: Search Excel, Excel for data analysis, Python Basics (University of Michigan), R programming

Topic 3	Medical Information Standards
Additional resources	• Vet-ICD-0-Canine-1, a System for coding canine neoplasms based on human ICD-0-3.2. Cancers (Basel) 2022: Mar; 14(6): 1529 • Cimino JJ: Desiderata for controlled medical vocabularies in the twenty-first century. Methods Inf Med 1998:37(4-5):394-403 *Online resources:* • DICOM, Key Concepts, https://www.dicomstandard.org/concepts/ • ICD-11 Fact Sheet, https://icd.who.int/en/docs/icd11factsheet_en.pdf • LOINC, https://loinc.org/get-started/what-loinc-is/ • NAHLN Information Technology System • SNOMED CT, https://www.snomed.org/snomed-ct/five-step-briefing • Veterinary Cancer Guidelines and Protocols: Synoptic Reporting in Veterinary Medicine https://vcgp.org/documents/2022/03/synoptic-reporting-in-veterinary-medicine.pdf/ • INHAND for Tox Path (https://www.toxpath.org/inhand.asp) • SEND (https://www.toxpath.org/send.asp)

Topic 4	Molecular pathology fundamentals
Additional resources	• Kenny EE, Bustamante CD. 2011. SnapShot: Human biomedical genomics. Cell. 147(1):248-248.e1 • Camp JG, Platt R, Treutlein B. 2019. Mapping human cell phenotypes to genotypes with single-cell genomics. Science. 365(6460):1401-1405 • Janardhan KS, Jensen H, Clayton NP, Herbert RA. 2018. Immunohistochemistry in investigative and toxicologic pathology. Toxicol Pathol. 46(5):488-510 • Keller SM, Vernau W and Moore PF. 2016. Clonality testing in veterinary medicine: A review with diagnostic guidelines. Vet Pathol. 53 (4): 711-725 • Malik YS, Khurana SMP, Barh D, Azevedo V eds. Genomics and Biotechnological Advances in Veterinary, Poultry, and Fisheries. 1st edition. 2019. Pages: 381-405. Bioinformatics for animal diseases: focused to major diseases and cancer

Topic 5	Digital Pathology

Additional resources	• Aeffner F, Blanchard TW, Keel MK, Williams BH: Whole-Slide Imaging: The Future Is Here. Veterinary pathology 2018, 55:488-9
	• Bertram CA, Klopfleisch R: The Pathologist 2.0: An Update on Digital Pathology in Veterinary Medicine. Veterinary pathology 2017, 54:756-66
	• Bertram CA, Gurtner C, Dettwiler M, Kershaw O, Dietert K, Pieper L, Pischon H, Gruber AD, Klopfleisch R: Validation of Digital Microscopy Compared With Light Microscopy for the Diagnosis of Canine Cutaneous Tumors. Veterinary pathology 2018, 55:490-500
	• Saravanan C, Schumacher V, Brown D, Dunstan R, Galarneau JR, Odin M, Mishra S: Meeting Report: Tissue-based Image Analysis. Toxicol Pathol 2017, 45:983-1003
	• Webster JD, Dunstan RW: Whole-slide imaging and automated image analysis: considerations and opportunities in the practice of pathology. Veterinary pathology 2014, 51:211-23
	• Zarella MD, Bowman D, Asteffner F, Farahani N, Xthona A, Absar SF, Parwani A, Bui M, Hartman DJ: A Practical Guide to Whole Slide Imaging: A White Paper From the Digital Pathology Association. Archives of pathology & laboratory medicine 2019, 143:222-34
	
	Online resources:
	• College of American Pathologists (CAP) Educational Resources (membership required)
	  ○ https://www.cap.org/member-resources/pathology-resource-guides
	• Digital Pathology Certificate Program by Digital Pathology Association (purchase required): https://digitalpathologyassociation.org/digital-pathology-certificate-program
	• Introduction to Bioimage Analysis: https://bioimagebook.github.io/
	• Digital Pathology Place Webinars https://digitalpathologyplace.com/webinar/
	  ○ https://digitalpathologyplace.com/podcast/what-the-heck-is-dicom-in-pathology-w-david-clunie-pixelmed-publishing/
	• ToxPath Webinars: https://www.toxpath.org/loginredirect.asp?Fn=/membersonly/webeducation.asp
	• https://www.pathpresenter.com/ sign up for free account, has exercises

Topic 6	Image Analysis
Additional resources	• Bertram et al., 2020. Computerized Calculation of Mitotic Count Distribution in Canine Cutaneous Mast Cell Tumor Sections: Mitotic Count Is Area Dependent. Vet Pathol. 57(2):214-226 • Chlipala et al., 2019. An Image Analysis Solution For Quantification and Determination of Immunohistochemistry Staining Reproducibility. Appl Immunohistochem Mol Morphol. 2019 May 16 • Webster and Dunstan (2014). Whole-Slide Imaging and Automated Image Analysis: Considerations and Opportunities in the Practice of Pathology. Veterinary Pathology, 51(1), 211–223 • Humphries, M. P., Maxwell, P., & Salto-Tellez, M. (2021). QuPath: The global impact of an open source digital pathology system. Computational and Structural Biotechnology Journal, 19, 852-859 • Jana S, Glabman RA, Koehne AL (2025) Bridging the gap between histopathology and genomics: Spotlighting Spatial Omics. *Veterinary Pathology.* PMID: 40138497 • https://digitalpathologyplace.com/8-free-open-source-software-programs-for-image-analysis-of-pathology-slides/

Topic 7:	Artificial Intelligence (AI)
Additional resources	• *Stanley Cohen (Eds) Artificial Intelligence and Deep Learning in Pathology. 1st Edition. Elsevier.*

	• Awaysheh et al. (2019). Review of Medical Decision Support and Machine-Learning Methods. Vet Pathol. 56(4):512-525 • Komura et al. 2018. Computational and Structural Biotechnology Journal Volume 16, 2018, Pages 34-42 • Landau and Pantanowitz (2019). Artificial intelligence in cytopathology: a review of the literature and overview of commercial landscape. J Am Soc Cytopathol. 8(4):230-241 • Saravanan C, Schumacher V, Brown D, Dunstan R, Galarneau JR, Odin M, Mishra S. Meeting Report: Tissue-based Image Analysis. Toxicol Pathol. 45(7):983-1003 • Kim D, Sundling KE, Virk R, Thrall MJ, Alperstein S, Bui MM, Chen-Yost H, Donnelly AD, Lin O, Liu X, Madrigal E. Digital Cytology Part 2: Artificial Intelligence in Cytology A Concept Paper with Review and Recommendations from the American Society of Cytopathology Digital Cytology Task Force. Journal of the American Society of Cytopathology. 2023 Dec 3 • Jarryd Lunn (2022): Artificial Intelligence, An Exiting Frontier & Friend for the Cytopathologist (https://www.youtube.com/watch?v=bITTPZxZ1MI) • Pantanowitz (2023): Digital Cytology & Emerging AI Applications https://www.youtube.com/watch?v=6rW1uG-3c28 • Introduction to Pathology Informatics: https://apai.memberclicks.net/teaching-slide-sets • Pantanowitz (2020): Pros and Cons of Artificial Intelligence. ACVP Webinar (https://www.acvp.org/page/Webinar_Archive) • Computational pathology Fundamentals - Pathology Outlines