Preparing for a Computational Pathology Future Through Informaticians and a Computational Technologist Workforce

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The significance of computation and informatics in pathology has gained recognition with the coinage of the term *computational pathology*. The concept of "computational pathology" emerged in 2008 in an article by Fuchs et al[1] and later expanded upon by Fuchs and Buhmann[2] in 2011. In the 2011 piece, computational pathology meant combining experimental design, statistical pattern recognition, and survival analysis within a unified framework to answer scientific and clinical questions in pathology.[2] With Louis et al[3] in 2016, the connotation of computational pathology evolved into taking raw data from multiple sources and extracting relevant information to make diagnostic inferences and predictions for optimization of medical decisions. That article further pointed to the necessity of attracting students and residents toward informatics. This piece dives well into that point in drawing bright minds to prepare for a computational pathology future.

Computational pathology starts with a foundation comprising those skilled in informatics. Before the establishment of accredited clinical informatics fellowships by the Accreditation Council for Graduate Medical Education, no formalized training for informatics careers existed. Standard medical education at the time did not delineate definable pathways or provide mentorship for pursuing informatics as a long-term career. As a consequence, the lack of direction in steering careers toward informatics produced missed opportunities to attract a significant number of creative minds.

Just having those skilled in informatics, although crucial, is insufficient to move toward a computational pathology future. Computational pathology extends on pathology informatics in leveraging innovative tools of deep learning and software development, the ramification of which requires informatics leadership to build and guide computational teams experienced in leveraging such modern tools.

Finding and attracting people skilled in informatics is hard. Finding and drawing expert people attuned to computation is even trickier and further demands smart approaches to spark interest and to recruit creative minds continually. Required is a formalized pipeline for talent to flow into computation pathology and strategies to empower such talent.

What Informatics Entails

Understanding what informatics entails permits the understanding of how it empowers talent in computational pathology. Informaticians provide the bridge in translating the highly innovative and technical into the practical. Informaticians use technology but are not just "technophiles," with technophiles being those who adopt technology at the "bleeding edge" without the considerations of how it fits into the greater context of medical research and practice.

Informatics is the art and science of "connecting." For instance, informatics entails connecting vast troves of data, historically housed in silos. Informatics likewise connects by application of knowledge domains beyond the technical into the greater context of medical research and practice. Such knowledge domains include operations, administrative structures, information flows, information technology (IT) frameworks, organizational cultures, and change management principles. Acquiring experience in informatics demands a curiosity, a hunger to familiarize, and the learning agility to shift seamlessly between these

different domains in their application. As the connectors, informaticians foster an interdisciplinary perspective to cultivate a broad knowledge base, leveraging their medical background but also an openness to venture beyond the comfort zone of formal medical education.

The sustainment of "creativity under constraints" is the challenge for informatics in today's health care. Informatics demands leadership to bridge and guide teams toward the development of solutions while overcoming the constraints of finite resources and rigid administrative, regulatory, and clinical frameworks. Inescapably, informatics entails integrating data in ways amenable to conceptualization and visualization to yield meaningful insights. This control of data, technology, and computation is where informatics and computational pathology intersect.

Informaticians Centrally Poised in a Future Computational Practice

Informaticians lay the fertile soil for computational pathology to take root. Pathology is poised to exponentially generate more data from throughput of image digitization and advanced molecular testing. Pathologists, regarded as "tissue gatekeepers" historically, will assume another role as "information gatekeepers" for the big data associated with the tissues.

Despite growth at unprecedented rates of pathology-related data, antiquated legacy information systems get deployed to clinical groups already overrun with too much data. Clinical teams are unreasonably forced to integrate and parse large amounts of data that have arguably surpassed the cognitive capabilities of human minds.[4,5]

Human minds have adapted to digesting data presented as visualizations (ie, graphs, charts, and visual aids). Contrast this to data presenting as narrative texts or strings of data that antiquated legacy information systems only accommodate. Due to dangers of information overload and lost opportunities for insights, incorporation of visualizations will soon be critical for future computational practice.

Informaticians appreciate that even the brightest human minds have difficulty parsing an information deluge. They equally understand the fundamental human cognitive processes involved to absorb elaborate clinically relevant data quickly. Likewise, informaticians value meaningful data integration from various sources and determine whether data satisfy both intuitive and computational requirements. The challenge resides in exploring new methods for data integration and presentation to avoid information overload.

Visual analytics is a computational science that addresses the torment of information overload. This science investigates advanced interactive visual interfaces to facilitate interpretation of complex data and combines concepts of data mining, machine learning, human-computer interaction, and human cognition.[5]

Informaticians are best positioned to integrate computational tools leveraging sciences like visual analytics due to their perspective on clinical needs and workflow requirements. Few, however, have the computational technical skillsets to develop such computational tools. Hence, informaticians must surround themselves with computational teams—teams comprising individuals analogous to the "quants" (short for quantitative analyst) in finance and the data scientists in computational biological sciences and Silicon Valley. These individuals create the fundamental architecture and software to tackle big data complexities in computational pathology and are skilled in programming, technical systems, data analysis, and higher mathematics.[6,7] Given that pathology has histotechnologists, cytotechnologists, and medical technologists, it seems germane to designate such individuals as computational technologists, being that such a term encapsulates those who are the new computational pathology counterparts of "quants" and data scientists.

Informaticians bridge the practical-technical chasm with computational technologists through leadership and communication of medical understanding to coordinate and develop computational tools. A challenge facing computational technologists is determining which data sets are useful while also exploring access and gathering data from unusual or unexpected sources.[7] Informaticians guide computational technologists to develop applications from their knowledge in the useful meaning of the data and in accessing data sources.

A future computational practice includes applications for computer vision, augmented decision support, and sophisticated integrated reporting leveraging sciences like visual analytics. These tools streamline assimilation of information by breaking down, simplifying, and intuitively presenting information in ways readily grasped by the human mind. It is through informaticians working with an established computational technologist workforce that allows for such a future computational practice to embark.

Building a Computational Technologist Workforce

For health care institutions, seeking and attracting the right talent to establish a computational technologist

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workforce is tricky. Because computational pathology goes beyond just informatics, the folly begins with using current IT technical support teams as a computational technologist workforce. Many organizations falter when starting internally with the recruitment of IT technical support teams due to easier availability.

Most IT technical support teams are familiar only with operations, end-user usability testing, and vendor partnerships. Such familiarity is suitable for traditional informatics-related endeavors. IT technical support teams still often lack skills needed to be computational technologists. As data scientists themselves, computational technologists must be experts at experimental design, forecasting, modeling, and statistical inference to produce meaningful insights with data. Unlike most IT technical support teams, computational technologists should also have the strong coding prowess to make use of meaningful data already in production, translating those programmatic tools back into clinical practice.[5] Computational technologists who embody all these areas of expertise are exceptionally rare, yet expecting such individuals to exist within IT technical support teams is an easy mistake.

Institutions fortunate enough to acquire individuals with computational technologist skills often lose them to better-compensated fields like industry, startups, and Wall Street. Compounding this loss is the substantial investment in cultivating computational technologists for pathology. Such investment understates the steep learning curves involved in acquiring pathology domain knowledge, as well as familiarity and organizational awareness with operations, administrative structures, information flows, IT frameworks, and work culture.

Informaticians must lead by mentoring and continuous propagation of such vision and knowledge. Also needed are formalizing pipelines for enticing and strategies to sustain such talent with the learning agility to handle such diverse demands.

Nursing schools and physician assistant schools affiliated with health care institutions provide a paradigm for a workforce pipeline in computational pathology. In enabling for a future era of computational pathology, health care institutions should affiliate with technical schools, fostering interest and engagement while recruiting promising computational technologists at the undergraduate and graduate levels. Computational talent who might otherwise enter Silicon Valley or Wall Street would instead tackle problems and challenges in pathology.

Affiliations with technical schools provide an added bonus with enhanced ancillary education for laboratory personnel such as medical technologists, empowering them with computational skills. Equally, health care alliances with technical schools offer physicians training in clinical informatics fellowships the opportunities to learn computational pathology skills, which supplement core training in traditional informatics.

Engagement in Informatics by Bringing Out Inner Informaticians

This article outlines a future era of computational pathology enabled through the creation of training pipelines and cultivation of a computational technologist workforce. Key to this blueprint is positioning informaticians center.

Pathologists get dissuaded from informatics because of misconceptions that only technophiles make good informaticians or that informatics fellowships and boards are required. In truth, informatics is a mind-set, and within every pathologist inhabits an "inner informatician," ready to engage computational challenges.

Technology is albeit one component of informatics, and understanding the human/social factors of people and processes is arguably more vital. Informatics needs pathologists who have organizational awareness and an appreciation for constraints. Informaticians have the intuition and balanced perspective on what is practical and what is achievable computationally and through available technologies. Especially now in the age of big data, informatics needs pathologists who understand the human cognitive components of taking in information and who can lead computational technologists to develop better visualizations for handling big data.

Pathologists who bring out their inner informaticians will disseminate their vision of how technological and computational changes can advance health care. Such leadership can only propel pathology forward toward a smarter future computational practice.

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