Abstract

Across a broad range of medical disciplines, learning how to use an optical or light microscope has been a mandatory inclusion in the undergraduate curriculum. The development of virtual microscopy (VM) technology during the past 10 years has called into question the use of the optical microscope in educational contexts. VM allows slide specimens to be digitized, which, in turn, allows the computer to mimic the workings of the light microscope. This move from analog technology (the light microscope) to digital technology (the computer as microscope) is part of the many significant changes going on in education, a singular manifestation of the broader move from print-literate traditions of knowledge (requiring literacy) to an electronics-literate, or “electrate,” mode (requiring “electracy”). VM is here used as an exemplar of this broad transition from literacy to electracy, some components of which include data deluge, a multimodal structure, and modularity. Understandably, this transition is important to clarify educationally, especially in a global context mediated via digital means. A related aspect of these educational changes is the move from teacher-directed learning to student-centered learning, or “user-led education,” which points to a redefinition of “pedagogy” as “andragogy.” The dissemination of the specific value of VM, then, is critical to both learners and teachers and to a more coherent understanding of electracy. A practical consequence of this clarity might be a better application of this knowledge in the evolving fields of computer simulation and telemedicine, areas in which today’s medical students will need future expertise.


In scientific–medical education and research, there is a strong tendency to concentrate on highly specified forms of data, usually of the quantitative variety. An instance of this in higher education is the student evaluations of learning and teaching that use the Likert scale to quantify opinions. A number of studies, originating from various universities and faculties around the world, have used quantitative methodology to help assess the widespread uptake of a new digital technique of microscopic analysis, virtual microscopy (VM). Generally, these have indicated a positive response to VM from learners and teachers alike. An understanding of the potential use and effectiveness of VM in both medical and associated educational contexts is important because both arenas are in a flux; it is critical in such contexts to encourage new ways of thinking and acting. In this article, we attempt to place VM technology in the context of this broad-brush paradigm shift, the most significant aspect of which is a move from a print-literate tradition to a digital electronic-literate or, more precisely, an “electrate” mode.

VM slides are digital representations of scanned glass slides that allow for the viewing, manipulation, and dissemination of these images of tissue specimens via computer, which of course makes them compatible with the World Wide Web (Web). Their digital format also makes VM slides part of the revolution in new media technology that is going on in both higher education and medicine. VM technology essentially transforms the computer into a microscope, a process that is yet another confirmation of the intermediating and integrating power of digital technologies. The glass slide for VM still has to be prepared via traditional means, but, once that slide is scanned into a digital format, there is very little change to its image structure; it can be replicated ad infinitum without any loss of quality. Moreover, given that the preparation of glass slides via sectioning produces incrementally different images of a particular specimen, VM technology is capable of making an exact replica of the section in question. A number of proprietary systems have been developed that can cope with the large amounts of data that a VM slide aggregates. Aperio Technologies, for instance, utilizes an algorithm that subdivides the data from a virtual slide into a number of smaller files that can then be smoothly loaded into the company’s viewer software. Once an image is opened in the viewing software, it can be moved across much as an optical slide is shifted, focal adjustment can be changed between 2× and 40× objective magnification, and a scale bar can be inserted to display micron length. The magnified region of the slide is accompanied by an image of the entire slide that sits in the upper right-hand corner, and a corresponding square box, showing the relative position of the magnified region, is superimposed on this larger image. This technology allows the opening of virtual slides over the Web. This shift from analog microscopic slides to VM slides is a highly significant development in our ability to magnify matter, and it is this magnification of matter beyond the realms of unaided human perception that gives us access to the quantum world.
Microscopic Data Go Digital

Whereas Einstein and other physicists are responsible for the discovery of the quantum world, in the more everyday circumstances of scientific and medical pedagogy, digitization has allowed an exponential explosion in the amount of data at our disposal. The representation of quantum worlds through microscopic magnification allows more scope for an immersion in data, a process that stands in stark contrast to the production of more objective, autonomous modes of knowledge, such as the scientific paper or the novel. This development inverts the usual emphasis in literate traditions on reality formation or on empirical or objective criteria (wherein data is mostly thought of as that which exists as a source of coherence and not as an object of interest in itself). VM technology sits at the cutting edge of this explosion in digital data, because microscopy (even in an analog format) has long been able to deliver a surfeit of data.

Ever since the 1660s, when Robert Hooke used a microscope to microimage cork and the compound eye of a fly, and Anthony van Leeuwenhoek examined his own animalcules (the voluminous bacteria in his mouth), there has been an ever-increasing amount of data picturing the microcosmos that is beyond human vision. With the advent of electronic systems of knowledge (which Gregory Ulmer has labeled “electracy,” as a combination of “electricity” and “literacy,” with a reference to Jacques Derrida’s idea of the “trace”)—roughly from the invention of chemical photography and telegraphy in the 19th century—it is now more thoroughly feasible to produce, store, disseminate, and recall such voluminous data. Furthermore, comprehension in electronic systems of knowledge transcends individual cognitive capacity, disciplinary categories, institutional formations, and even national boundaries. Electracy, then, is the big picture, or gestalt category, within which we can more fully comprehend teaching, learning, and the production of knowledge at this current juncture of history.

From Literacy to Electracy

What even a detailed, quantitative, and sometimes technical analysis of VM usually omits, however, is an examination of the big picture or “wide image”—meaning, in this case, the broader educational context. VM, articulated through the digital computer, is quite obviously an electronic technology. The long history of human communication—and, thus, pedagogic—arrangements is widely considered to be tripartite: oral communication, literate (print-based) communication, and electronic communication. Oral communication is generally recognized as characteristic of indigenous societies. Literate, print-based communication is generally attributed to more nationalist forms of social and political organization. Electronic communication is usually attributed to a more globalized society and polity. In corresponding educational parlance, these three categories of communication (and pedagogy) can be labeled oracy, literacy, and electracy. The shift from light (or optical) microscopy to VM, then, is also a case study in this shift from literacy to electracy. Given the current centrality of computing technology to scientific–medical knowledge, those educators and students broadly involved in the medical and health sciences might benefit from an explanation of this big-picture paradigm shift.

With the advent of a critical mass in new media technologies, the very question of literacy itself is now loaded with uncertainty, as indicated by the extended debates that currently surround the topic. One response to this uncertainty about literacy is in the division of the term into many new subcategories, mostly as a means of responding to these new electronic technologies and practices: media literacy, digital literacy, information literacy, and technological literacy are just some examples of this development. Ulmer calls this response into question when he writes, “To speak of computer literacy or media literacy may be an attempt to remain within the apparatus of alphabetic writing that has organized the Western tradition for nearly the past three millennia.” Given that the social and political conditions, as well as the technology associated with electronic communication, allow for a substantial realignment of both cognitive processes and the means of representing those processes, literacy no longer be an adequate framework through which to organize knowledge and disseminate it to students. If print technologies were more mechanical—or “linear indexical”—in their orientation, then electronic forms of knowledge are what could be considered “modular” technologies and practices; this development encourages the rising to prominence of a “network-associational” logic. Phrasal nouns such as “information literacy,” then, are inadequate in defining and categorizing electronic pedagogy, because the word “literacy” is so closely aligned to linear indexical logic. Thus, the term “electracy” is meant to represent a means of thinking, producing, and disseminating knowledge in an electronic fashion.

Modularity is the ability of the subcomponents of an electronic system not only to act semiautonomously but also to link up with other systemic components and to do so not simply in a linear or hierarchical way but in utterly dynamic, layered, spatially and temporally variable, or even accidental or three-dimensional ways. Modularity, as a key educational feature of electracy, undermines clear-cut universal categories and encourages the intake and production of knowledge in more individualized, idiosyncratic ways. That is, electronic technologies and practices provide for a “this goes with that, goes with this, goes with that” frame of reference; as a means of organizing knowledge, network associational logic mirrors ideas in evolutionary psychology that are grouped under the term “modularity of mind.” Aided and abetted by a conceptual modularity of mind, this shift from linear indexical to network associational models of pedagogy has also helped underpin the emergence of a broad range of learning paradigms that have come to be associated with the take-up of new media in higher education.

Learning and Teaching Electronically

This shift from linear indexical to network associational thought goes to the very heart of the changes in learning and teaching that we discuss here. The phrase “linear indexical thought” is clearly another way of saying sequentially coherent logical reasoning sequestered into tightly constrained authorial sources by gate-keeping and editorial protocols. As a means of organizing knowledge, linear indexical thought is the very
foundation of traditional scientific and medical thinking. Network associational thought, on the other hand, more accurately mimics affective modes of reasoning—that is, emotional intelligence. Ulmer, citing work on artificial intelligence by Jeremy Campbell, writes that this is “reasoning with memory rather than logic.” Whereas linear indexical thought is mostly a product of independently verifiable expert analysis, network associational logic relies more obviously on memory, intuition, and the context of a specific learner and teacher.

Linear indexical thought is also strongly associated with a didactic or injection model of learning or, as Terry Flew explains it, a “one-way mass distribution model of education, where content is created by the provider and disseminated to the learner.” This shift to network associational thought patterns, in contrast, moves the pedagogical emphasis more toward student-centered styles of learning, one of which is social constructivist in orientation. Social constructivist forms of learning emphasize the actively dynamic cognitive engagement of the learner and the ways in which learners construct knowledge for themselves, by using a wide range of variable triggers from memory, context, disciplinary protocols, and content variations, among other elements.

Jonassen and colleagues identified a range of attributes of constructivist modes of learning: (1) “knowledge is constructed, not transmitted,” (2) “is embedded in activity,” (3) “is anchored in and indexed by the context in which the learning activity occurs,” (4) “meaning is in the mind of the knower,” (5) it provides “multiple perspectives on the world,” (6) “is prompted by a problem, question, confusion, disagreement, or dissonance,” (7) “requires articulation, expression, or representation of what is learned,” (8) “may be shared with others,” (9) “meaning making [i.e., the creation of meaning] and thinking are distributed throughout our tools, culture, and community,” and (10) “not all meaning is created equally.” One well-known example of constructivist pedagogy is Michael Faraday’s lectures on “The Chemical History of a Candle,” delivered to the Royal Institution in London in 1860. Faraday used a simple, open-ended, process-orientated method to illustrate basic scientific principles such as combustion, capillary attraction, and the properties of heat and light, while also engaging in easily replicable experiments to illustrate these principles for his audience. Faraday’s lecture also suggests that social constructivist forms of pedagogy are not new but, rather, have been with us for some time.

As Walker and colleagues suggested, “An open classroom is one where students conduct experiments and then develop explanations for the phenomena they see, instead of being given an explanation by the teacher that they then have to ‘prove’ is right through experimentation.” By all accounts, Faraday was an inspired and inspiring teacher who had an obvious enthusiasm for his subject and who, in using the simple example of a burning candle, was able to ignite the imagination of his young audience. It is perhaps when the imagination of the learner is profoundly activated and engaged that social constructivist pedagogy opens the way for deep learning to occur. The question might also be asked as to whether Faraday’s well-known discovery of the connection between magnetism, electricity, and light had some bearing on his style of teaching and learning. By dint of engaging the whole affective body of the learner, rather than just the cognitive faculty, might Faraday’s pedagogic exemplar be indicative of the electrate person, in the way that a silent reading of a novel or of numbers serves as an exemplar of the literate person?

**VM as an Electrate Practice**

At this point in the discussion, we return to the interaction of electracy with VM technology. Quite obviously, VM provides learners and teachers with visible evidence of biological material mediated via digital means. Also accompanying this shift from literacy to electracy are both the already-mentioned data explosion and an expansion in the modalities of knowledge that digital media make available to learners and teachers. Rather than just textual or print material, an electrate framework provides for a learning space in which image, sound, and text are available, and, indeed, sometimes the three modalities intermingle, instigating another level of modularity. As W.J.T. Mitchell wrote, “Media are always mixtures of sensory and semiotic elements, and all the so-called visual media are mixed or hybrid formations [author’s italics], combining sound and sight, text and image. Even vision itself is not purely optical, requiring for its operations a coordination of optical and tactile impressions.” This point about the “multimodal” character of electronic communication is also made by Kress and Van Leeuwen and is a feature that allows for the simultaneous but differential presentation of these three broad modalities in any given learning and teaching situation.

In light of this three-modalities framework, it might also be noted here that VM slides allow for written annotations and graphic overlays (in the form of measurement indices) that are then easily incorporated into their internal display for pedagogic or other purposes, while at the same time allowing the original copy of the slide to remain intact. Saved as a digital file, this duplication then becomes amenable to incorporation into, for example, a Word, PDF, or PowerPoint document. Optical microscopy does not allow for such creative educational engagement with a slide, and thus this feature is a significant enhancement of the learning process. This tripartite structure of electracy is a significant evolution from the highly influential Ramus method so endemic in higher education and commonly described as textbook-articulated knowledge. VM technology allows for a virtual space within which the learner can explore the pedagogic possibilities inherent in the specific slide under consideration, a situation that might make the teacher as much a tour guide as an instructor.

It is also this expansion in the range of modalities framing electracy that prefigures the wide range of learning styles and methods that have come to prominence of late. Thus, an electrate person learns not only from a written textbook (the Ramus method) or a lecture or even an exclusively conceived social constructivist method in electronic contexts, as Torrisi-Steele suggested. Electronically articulated methods of learning and teaching are wide-ranging and can include such processes as lifelong learning, experiential learning, Podcasting, collaborative learning,
problem-based learning, and, more pertinently, what Willis termed an “algorithmic pedagogy.” Largely in contrast to a unitarily conceived literate method, an electrate pedagogy promotes a wide diversity of methods through which a learner’s knowledge of a subject or discipline is acquired. The shift from the analog light microscope to the virtual microscope in medical education, then, is clearly part of this broader change in educational methods—the shift from literacy to electracy.

It is equally important to note that, largely because of electracy’s tripartite modular structure, there is also a potential electronic synthesis of the already-mentioned three paradigms of human communication—oracy, literacy, and electracy—or at least those modalities that are amenable to digitization. This synthesis is especially apparent in the computer’s ability to turn a file’s written content into an audio rendition and in the commonplace print literacy-based terms “desktop,” “folder,” and “file” that are used in relation to computer interface design; the print-evocative terms “MacBook Pro” and “Notebook” also are worth reconsidering in that context. Indeed, an electrate frame of reference for learning and teaching not only substantially increases the amount and variety of data at one’s disposal, it inaugurates an ability to coordinate various elements of oral, literate, and electronic frameworks into a digital environment. In pedagogic work involving VM, this clearly is a learning opportunity worth pursuing.

VM as a Learning Space

The mention of VM as a virtual space also opens the debate to include the notion of a “learning space,” a concept that does not always have to be interpreted in architectural terms. To the uninitiated, in contrast to a scientific or a medical analysis of a slide (virtual or analog), a computer-mediated slide, considered as a learning tool, is of a different order. The vast majority of students first come to microscopic imagery with little or no specific idea of what it is that is being represented. This makes the initial interpretation extremely difficult until such time as familiarity and experience reach a deeper level of understanding. Promotion of the idea of a virtual slide as a multimodal learning space might itself help reduce the anxiety many learners feel in their first contact with this unfamiliar knowledge.

As in all things spatial, multiple elements reside in simultaneous proximity, and so it is with the virtual slide. What is it among the various juxtaposed elements that requires concentration and elucidation? What relationships are set up by the possible interaction among these elements? A given group of students can work on the same virtual slide together, which is not possible with a light microscope, and, thus, not only does the content of the slide constitute the learning space but the learning potential of the group in their social interactions also forms a component of that learning space, that is, the socially mediated learning possibilities that any given slide constitutes. A learning space, then, is constituted not only by the physical space in which the slide is viewed, discussed, and interpreted but also by the social interaction generated by the learner’s use of a specific technology in that space.

Indeed, because of the group-focused, educationally interactive potential of many electronic learning and teaching practices, and to emphasize the collaboratively integrative potential of such practices, James Paul Gee goes so far as to propose the idea of an “affinity space,” rather than a learning space, as a “community of practice.” Of course, Gee is referring to video games, but there is a striking resemblance between slide imagery and gaming imagery, especially in the ability of both to render user choice in relation to finer and/or larger focal attenuations. It may then be helpful to posit the potential of VM (in the initial learning and teaching stage at least) as the basis on which an affinity space could be developed, rather than proceeding directly to a scientific or medical analysis. Professional competence in interpreting slides is a matter of long-term experience, and, in the initial stage of learning, an interpreter has little of that expertise. As a means of examining their own pedagogic methods, it may even be helpful for teachers themselves to assume that they have this professional ignorance. After all, a self-reflective method is essential to the development of a refreshed pedagogic practice both for students and for teachers.

Pedagogy Into Andragogy

In the electrate era of learning and teaching, even the very definition of “pedagogy” has come in for further questioning and refinement. Malcolm Knowles made the distinction that, whereas “pedagogy” is an educative process primarily related to children (because of the word’s close semantic affinity with the word element “paed-,” as in paediatric), the term “andragogy” is more appropriate to adult education. Taking a cue from Knowles’s work, Stewart Hase and Chris Kenyon coined the term “heutagogy,” which they define as “being concerned with learner-centred learning that sees the learner as the major agent in [his or her] own learning, which occurs as a result of personal experiences.” They go on to say, “The teacher might think that he or she can control the learning experience, but we think the teacher’s role is limited to the transfer of knowledge and skills.”

Hase and Kenyon created “heutagogy” by combining the Greek word heurētikos with pedagogy. The pertinent definition for heuristic, from The Oxford English Dictionary, is “the educational principle or practice of placing a pupil, as far as possible, in the position of a discoverer”; it is also an educational principle that Ulmer asserts is a defining characteristic of electrate knowledge. “Heutagogy” (Ulmer uses the term heurētikos) is the educational philosophy that sits at the very heart of the move from teacher-centered, didactic, or literate modes of learning and teaching to student-focused, electrate modes, which are disseminated in the main but not exclusively via the Web. This heuristic principle is also at the heart of a “user-led education,” a means of thinking about an electrate pedagogy that uses the term “produsage” (which can be defined as “user-led” content creation) to indicate we are all simultaneously both consumers and producers of information and knowledge in both educational and entertainment contexts.

Return to the Beginning

Hase and Kenyon’s placement of “heutagogy” in the framework of complexity theory returns us to the beginning, in this case to the scientific method central to a university education itself. As Doll explained, the “new sciences” of chaos theory, string theory,
fractals, emergence, cybernetics, quantum theory, nonlinear dynamics, and so on have collectively proven to be a revolution in the static, objective, numerical calculation favored by the traditional scientific method. The electronic technologies associated with electrate-style learning promote a more open, dynamic, relational, creative, systems-orientated approach to learning and teaching. This is not to say, however, that the traditional scientific method is obsolete. On the contrary, both qualitative and quantitative methods are significantly heightened in the context of a student-centered, electronic, global view of education. Brian Massumi even goes so far as to say, “The fact of the matter is that the humanities need the sciences ... a lot more than the sciences need the humanities.” Whereas this assertion may be questioned, humanities-focused educational thinking has borrowed extensively from the new sciences to articulate the emergence of the various already-mentioned pedagogies appropriate to electrate knowledge.

VM technologies and practices have emerged in the medical curriculum during the past 10 to 15 years, and thus they are clearly a component of this idiosyncratic combination of both a scientific–medical paradigm and an arts–humanities orientation in education. Our own published observations of student evaluations of VM usage in our courses have identified many educational advantages, such as greater image resolution and magnification potential, improved collaboration among learners, and added variety in ways of course delivery (e.g., online); some students even admitted that virtual slides are fun to learn with. If, as educators, we are more acutely aware of these broader philosophical, social, and psychological issues as they affect education’s form and content (scientific or humanist and qualitative or quantitative), we will be better equipped to harness the extraordinary possibilities of this electronic technological revolution going on in learning and teaching in our schools and universities and, more broadly, in our society. The more comprehensive and sophisticated understanding of electronic pedagogy that electracy offers (the complexity of which we can only touch on here) is such a paradigm for framing a deeper understanding of the quantum data of the microscopic world depicted by VM.

By now, the far-reaching changes going on in both medical and education contexts should be apparent to us all; we have been able here to point to only a small number of these changes. The pervasiveness of electronic technologies and practices in these contexts, merging with and now overtaking literate technologies and practices, should alert us to the urgent need for a concomitant conceptual innovation. Indeed, it could be argued that the network associational logic accompanying these technologies and practices creates a situation in which permanent innovation is a necessity, not just a cyclic or periodic phenomenon. As Gibbons and colleagues pointed out in The New Production of Knowledge, the information and communication technology revolution helped instigate a more thoroughgoing integration of theory and practice in real-world contexts. A more sophisticated understanding both of VM as an exemplar of electracy and of the broader paradigm shift to electracy itself has many practical outcomes, as in patient record keeping, computer simulation, the promotion of continuous learning, the interpretation of medical imagery, telemedicine, and reinvigorating the engagement of students and medical workers alike. This ongoing transition from literacy to electracy is a necessary innovation that is bringing its own set of difficulties, but it is an innovation that we must ultimately face, articulate more thoroughly, and address with newly formulated policies.

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