

# A Return to Polymathy

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*Never delegate understanding.* –Charles Eames

Universities have an opportunity and an obligation to train polymaths. The opportunity comes from the emergence of new foundations that unify fields. The obligation arises because humanity's pressing problems are not neatly confined within academic disciplines. However, the divisive organizations of academic departments and curricula make it hard for faculty and students to understand systemic problems such as climate change, biological diversity, sustainability, and poverty. Universities might be judged harshly in future for promoting specialization and a cult of expertise when they could have been training new generations of scholars to understand systems as systems.

Polymathy was common until specialization pushed it aside, and made interdisciplinarity necessary. The relative frequency of the term “interdisciplinary” has grown since 1940, whereas the term “liberal arts” has declined from its peak frequency in 1962, just five years after Sputnik. To me “interdisciplinary” connotes a problem, not a solution. The problem is that academics generally do not work across disciplines. The solution I will explore here is polymathy.

Polymaths don't simply know a lot, they understand what fields have in common. Polymaths understand that disciplines share foundations (historically, natural philosophy and mathematics) that, once mastered, make the master interdisciplinary.

What makes our new century so exciting, and so challenging for colleges and universities, is the emergence of *new* foundations, as well as a new appreciation of the power of foundations (new and old) to unify disciplines as they come to grips with complicated systems. Foundations such as information, grammar, feedback, utility and their associated mathematical and computational methods will always be needed to solve discipline-specific problems; but they also can illuminate what disciplines have in common, so that by training students in new foundations we train them for interdisciplinary work. A linguist might say that academics today speak pidgin and our job is to create creoles, a new generation of scholars that speaks not a halting jumble of shared goals and concepts but a real language that captures the breadth and beauty of ubiquitous, fundamental ideas.

I met some members of the new generation at the 2014 q-bio Summer School and Conference. The aims of q-bio include: “advancing predictive modeling of cellular regulation, decision making, formation of response, and other information processing phenomena.” Only the word “cellular” is specific to biology, the other words denote universal abstractions. For instance, the processes of regulation – sensing one's state, computing a disparity between that state and a desired state, deciding on a response – manifest at every level of organization of biological systems, as well as in engineered systems, economic systems, and systems of many other kinds. System-specific pathologies of regulation such as uncontrolled cell proliferation, flash crashes in markets, and accelerating melting of the polar ice caps, which look different superficially, may look similar or identical when framed in terms of the processes of regulation. Abstractions like regulation are what fields have

in common. They are the foundations of interdisciplinary work because they help experts in different fields communicate and, more importantly, they help a new generation – exemplified by the students at qbio – become polymathic, that is, able to work in multiple fields.

Some new foundations aren't actually new, but they are not yet taught as abstractions that unite disciplines. Evolution by natural selection is an old idea that plays not only in natural systems but also in markets and computer programs that evolve other programs. The fundamental model of data and an appreciation of variation underlies virtually all disciplines, but you'd never learn this in your average statistics course. The idea of a code whose purpose is to communicate a message has been profoundly productive but today is taught mostly in electrical engineering departments. Students in those classes think that communication is mostly about efficiency and error correction. I doubt that professors in communications departments would agree. It seems that the great abstractions were dumped into the top of a pachinko machine and sorted into departments to be taught in narrow ways. The idea I am calling new foundations begins by up-ending the machine and sorting through the balls, rubbing off the discipline-specific tarnishes, and teaching these brilliant ideas as unifying.

There must also be unifying abstractions in humanities and the arts to be taught alongside those from the sciences. They might be more qualitative than, say, entropy or feedback, but they are still abstract, unifying ideas. I learned in my dad's undergraduate art history class that representation is hard intellectual work, that verisimilitude isn't always a goal, that every representation favors some aspects of what it represents, and that cultural context influences what we extract from representations; lessons that have helped me as a researcher in artificial intelligence. Later, I learned that visual perception is constructive – we see what our brain makes of sensory information, not necessarily what's there – which fascinated the art historian Ernst Gombrich and led to his concept of “the Beholder's Share,” a phrase that should be repeated as a mantra by anyone who thinks that Big Data speaks for itself. As a psychology student I learned that “top-down” or “expectation-driven” processes can control the proliferation of incorrect hypotheses generated by “bottom-up” or “data-driven” processes – which is probably why perception is constructive and we have a Beholder's Share – a lesson that seems lost on today's data-driven technologists who think the only possible computational architecture is the pipeline, despite its stubborn error rates in perceptual tasks such as automatic speech recognition and scene analysis. To those who fret about the Uncanny Valley, who wonder why Walt Disney's hand-drawn mouse is still more engaging than some CGI blockbusters, who find statistical analyses of J.S.Bach or Jackson Pollack to be lacking something (or, worse, to be *not* lacking something) I recommend an art history course.

This isn't quite right, because art history, like other academic disciplines, is taught in a discipline-specific way. What I'd like is a course that identifies the great, abstract ideas that emerge from millennia of art-making. These abstractions are probably very general, so they probably tell us something about what art has in common with other fields.

New foundations – abstractions that help us understand what fields have in common – challenge universities to rethink general education requirements. Today we feed students some “breadth” (typically a selection of introductions to different academic disciplines, a mere nod in the direction of a liberal arts education) then herd them down disciplinary chutes. Can we imagine teaching students to be polymaths? Polymaths can walk into any environment – any studio, lab or other workplace – and say, “Yes, I understand, I've seen that before: To you, it's a railway network; to me, it's a Steiner network, similar in useful ways to the graphs produced by the growth of slime molds. I wonder how efficient your network is, relative to one that might be created by slime molds?” Can we teach students to appreciate not the superficial differences between fields but their deep, abstract similarities? Which is more important, learning the periodic table of the elements or learning that the elements can be organized in a systematic way, just as syntactic categories can

be organized in a systematic way; and that the organization – in chemistry, linguistics and other fields – emerges from explaining how smaller units compose into larger ones?

This is a tough time to preach polymathy, with academic disciplines so deeply entrenched in their departments, jealously guarding their student credit hours, insisting, often correctly, that their courses of study are so demanding that they leave no time for other pursuits. What’s the difference between a jazz musician and a large pizza, asks my friend Kelland Thomas, an acclaimed musician who also earned a degree in computer science? The pizza will feed a family of four. With big disparities in the incomes of professors and the status of their fields, who is in a mood to talk about polymathy?

For all its faults, the academy still attracts idealists, and I was fortunate to work with a dozen of them – including Kelland Thomas – at the University of Arizona, where we created the School of Information: Science, Technology and Arts (SISTA), dedicated to teaching students the new foundations and technologies of the Information Age. One of our first decisions was to create the entire undergraduate curriculum from scratch instead of mashing together extant, disciplinary courses. Our core courses are: Great Ideas of the Information Age, Statistical Foundations of the Information Age, Computational Thinking and Doing, Ethics in a Digital World, Dealing with Data (not a database course but a general introduction to data as the fuel of the Information Age), and Empirical Methods (a project-based course where students learn research methods). We also teach “thematic” courses that examine one ubiquitous theme in an interdisciplinary way. One is about the ubiquitous methods of Bayesian inference, evidential reasoning and skepticism. Another examines learning: human learning, machine learning, animal learning and so on. We taught a course called The Image, studying images from the perspectives of computer vision, perception, art history, childrens’ drawing, and so on. If we had the resources, we would also teach courses about properties and mechanisms of systems such as Regulation, Robustness and Control, and ubiquitous structures such as Sequences, Trees and Graphs. None of these is a disciplinary course.

SISTA’s short history taught me that four problems must be addressed if we are to teach new foundations and polymathy.

First, although many new foundations are associated with computer science and what’s been called “computational thinking,” students should not have to take computer science degrees to learn these foundations. Mathematics departments teach foundations without requiring students to get mathematics degrees; computer scientists, along with statisticians, biologists, linguists, philosophers, and other “digital x” faculty will have to figure out how to teach students to be informed citizens of the Information Age. University leaders should look skeptically on claims that only computer scientists can teach this stuff, especially as many computer scientists don’t actually know it, or even consider it to be computer science. (What fraction of an average computer science faculty knows statistics? What fraction of the new foundations are essentially statistical and probabilistic?)

Second, new foundations are abstractions, and not all students are good at abstract thinking. I designed the “Great Ideas” course mentioned earlier, drafted an accompanying text, and taught it at the 100 level. I covered the relationship between structure and function, the idea that information structures can evolve or be designed to do particular kinds of work, just as physical things are. Also included: elementary probability and how probability expresses the structure of information; elementary data structures and algorithms; some information theory; why similarity matters and how it is measured; elementary Bayesian inference; a bit of decision theory; all leading up to the idea of agency as exemplified by devices, humans and other animals. Five professors have taught the course with varying degrees of success, and I think now that it is too abstract for 100-level students. If we are going to teach polymaths, we will have to think about when and how to introduce abstractions.

Third, academics will argue endlessly about which abstractions should be taught and who is

qualified to teach them. My course and text reflect my experience and education; others would teach a different curriculum. SISTA surely has not figured out the “right” curriculum in new foundations, but it made a good start.

Fourth, an old blueprint holds many colleges and universities back. It assumes that knowledge is best organized hierarchically and educational institutions should have a congruent organization. People are hired to correspond roughly with nodes in the received tree of knowledge. The higher your node is in the tree the more resources you have to distribute. Then along comes something utterly ubiquitous – Big Data is a recent example – and the first question according to the old blueprint is, who owns it? Well, everyone does, so there’s a mad and uncoordinated scramble, and elbows fly, and people behave badly, when what’s really needed is a coordinated, visionary, institution-wide response from university leaders.

If these challenges are daunting, consider feeding nine billion, universal education, energy security, aging and healthcare, all of which refuse to confine themselves to one system, let alone one academic department. These challenges require colleges and universities to be flexible and agile – like the huge research-based corporations that increasingly eclipse us – yet that old blueprint still controls us. Academic departments are run by and for specialists. With every academic field splintering into more subfields than any department can cover, the imperative will always be to strengthen a subfield or add a new one. Bridging between academic disciplines runs a distant third, and responding to major challenges as an institution is rarely on the radar. You can’t blame department heads for trying to maximize their utilities; all you can do is change the payoffs. That’s a job for university leaders.

If one is looking for a single label to encompass many of the new foundations – perhaps to form a new school or department – I would suggest Systems. Not Systems Science (excluding engineering, humanities and the arts) or Systematics (the study of evolutionary relationships between species) but plain old Systems. It reminds us that everything we study is part of something bigger; it encourages us to look up, not deeper down; it elevates the study of systemic properties such as robustness; and it reminds us how desperately we need to model and understand the big systems on which we depend. A School of Systems would encompass natural, social, economic and engineered systems, as well as epistemic systems of knowledge and thinking. With a curriculum in new foundations, Systems could dispense with unhelpful distinctions between academic disciplines and give the students and faculty who want one a natural locus for interdisciplinary research.

Those colleges and universities that figure out how to organize research and teach new foundations and polymathy and prepare their students to understand a world in which every system, at every scale, acts causally on others, will see their stock rise. The rest will struggle to remain relevant.