WHEN THINGS START TO THINK | Chapter 13: Information and Education

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Nicholas Negroponte is the visible face of the Media Lab, an articulate advocate of being digital. Far fewer people know of Jerome Wiesner's role. Jerry was MIT's president, and Kennedy's science advisor. He's been described as the member of the administration during that exceptional era who was not only smart, but also wise.

As I started attending faculty meetings I soon discovered that Jerry was even more bored with them than I was. If I sat next to him he would tell me stories, like how the debate in the meeting we were ignoring mirrored a fight he had had in the Cabinet. Through these discussions I learned a secret: the Media Lab is really a front for an even more interesting project.

After a lifetime of shaping science, Jerry felt that there was a big hole in the middle of academia in general, and at MIT in particular. Disciplines were kept apart, basic and applied research happened in different places at different times, and industrial interaction was based on handing off results rather than intimate collaboration. Most serious of all, content of many kinds had no place on campus. As a physicist in a normal department I could look at transistors, but not toys. I might see industrialists, but not artists.

The Media Lab was his last grand project, a meta-experiment in organizing inquiry for a new era. He knew that this goal was so interesting and important that he could never really discuss it openly. There would be too many conflicting interests for it ever to be accomplished by a committee. Instead, Nicholas and his colleagues at the predecessor to the Media Lab, the Architecture Machine Group, provided the perfect research agenda and working style to create a laboratory laboratory.

It took me a long time to recognize this hidden project. When I started visiting, I didn't see the Media Lab as a place to do serious science; it was an entertaining diversion from the real work that I was doing elsewhere. I expected to eventually go to an industrial laboratory to set up my research group (I had found that I was too practical to be happy in a traditional academic setting). And Nicholas certainly didn't see the Media Lab as a place for something as dry and remote as a physics lab.

When we finally sat down to talk, he told me a story to explain his surprise at the prospect of my coming to the Media Lab. He said that if there was a monastery on top of a hill, and a brothel down in a valley, he wouldn't expect there to be too much traffic between the two institutions. I was struck by this image, but for the life of me I couldn't figure out which lab was which. I'm even less sure now.

The more we spoke, the more we realized that it did make sense for the Media Lab to have a physics group. For me, it would provide the support to work on physics in the new domains where it is needed. I knew how to do physics; the hard thing was getting access to the emerging context. For Nicholas, it would provide the tools and techniques to help open up computers and move information out into the world where it is needed.

In retrospect I'm embarrassed by how long it took me to decide that it was okay to have fun for a living. I had been trained to believe that the sorts of things I had been doing in the Media Lab, like working on Yo-Yo's cello, were done on the side by serious scientists, not as part of their day job. I thought that trying to do physics outside of a Physics department was going to be a radical and uncertain step.

I realized that it was going to work when students started showing up, explaining that they loved physics, but that they knew they did not want to study it in a traditional department. They were unwilling to disconnect their personal passions from their intellectual pursuits, and they did not want to follow a conventional academic career path with limited prospects for funding and employment. This was brought home one day by a headline in MIT's campus newspaper, "Cutbacks Announced in Dance and Physics."

I was also concerned about where my students would publish their research papers; I had expected that we would have to dissect out the pure academic nuggets from the impure context. Here again I realized that this was not going to be a problem when journal editors started showing up in my lab to solicit submissions. They recognize that the world is changing, and they don't want to keep publishing the same kinds of papers.

As my lab grew, my biggest surprise was watching how my students were reinventing the organization of their education. Scientific training has traditionally been based around extensive classwork, illustrated by occasional labs. My students were turning that inside out.

That they were in my lab at all was due to Edwin Land, the founder of Polaroid. He felt that MIT's undergrads should be in working laboratories participating in real research as it happened, rather than doing rote repetitions in lab classes long after the fact. He provided the seed funding for a very successful program to do just that.

The undergrads in my lab used it for far more than what Land originally envisioned. It became their home, the place where they learned to work with people and use disciplines to solve hard problems. Their classes took on a supporting role, providing the raw material that got shaped into an education in my lab. Over and over they told me that they had no idea why they were being taught something until they got to use it in one of our projects. For them, this experience was more like being in a studio than a classroom.

I found that one of the best predictors of a student's success working this way was their grades: I look to make sure they have a few F's. Students with perfect grades almost always don't work out, because it means they've spent their time trying to meticulously follow classroom instructions that are absent in the rest of the world. Students with A's and F's have a much better record, because they're able to do good work, and also set priorities for themselves. They're the ones most able to pose—and solve—problems that go far beyond anything I might assign to them.

The present system of classes does not serve the students, or their teachers, very well. One week an MIT undergrad, and independently an MIT professor, asked me the same question: how does the bandwidth of a telephone line relate to the bit rate of a modem? The bandwidth is the range of frequencies a phone line can pass, which is set by the phone companies and regulatory agencies. The bit rate is how fast data gets sent, all too noticeable as the speed with which a Web page loads. They were wondering how the bandwidth affects the bit rate that can be achieved, and what the prospects were for faster modems.

This is the problem that Shannon solved in the 1940s with his theory of information: the maximum possible bit rate is the bandwidth times the logarithm of one plus the ratio of the strength of the signal to the amount of noise. The bit rate can be improved by using more frequencies, by sending a stronger signal, or by decreasing the noise. Modems are now near the limit of a conventional phone channel, although the wires themselves can handle data much faster.

I was surprised to find that someone could be at MIT as long as both the student and professor had been, studying communications in many forms, and never have heard of a result as important as this. Not only that, both were unprepared to understand where it came from and what conclusions might be drawn from it.

Entropy shows up in two places in their question, in analyzing the noise that is intrinsic to the materials in a telephone, and in analyzing the information that can be carried by a message sent through the telephone. Although these two calculations are closely related, physicists learn how to do the former in one part of campus, and engineers the latter in another. Very few students manage to be sufficiently bilingual to be able to do both. Those who are either take so many classes beyond the usual load that they manage to squeeze in a few different simultaneous degrees, or take so few classes that they have enough time to put these pieces together on their own. Either path requires unusual initiative to answer such a reasonable question.

Faced with students who knew a lot about a little, I decided that I had to teach everything. This took the form of two semester-long courses, one covering the physical world outside of computers (The Physics of Information Technology), and the other the logical world inside computers (The Nature of Mathematical Modeling). My students loved them; some of my peers at MIT hated them. This was because each week I would cover material that usually takes a full semester.

I did this by teaching just those things that are remembered and used long after a class has ended, rather than everything that gets thrown in. This starts by introducing the language in an area so that the students, for example, know that bit rate and bandwidth are related by Shannon's channel capacity. Then I cover enough of each subject to enable students to be able to understand where the results come from and how they are used; at this point they would know how to calculate the channel capacity of a simple system. Each week ends with pointers into the specialized literature so that, for example, students learn that Shannon's limit effectively can be exceeded by taking advantage of quirks of human perception. Although this brisk pace does a disservice to any one area, unless I teach this way most people won't see most things. It is only by violating the norms of what must be taught in each discipline that I can convey the value of the disciplines.

What connects the work in the Media Lab is a sensibility, a style of working, a set of shared questions and applications. It's not a discipline, a distinct body of knowledge that has stood the test of time and that brings order to a broad area of our experience. Progress on the former relies on the latter.

In many places computers are studied in separate departments, meaning that students who like computers get less exposure to mathematics and physics, and hence can have less insight into how computers work. This can result in their using the wrong tool for the wrong problem, and in their being unable to distinguish between hard things that look easy and easy things that look hard.

A number of computer scientists have told me that they want to mount display screens in glasses. They know that the eye cannot focus on something so close, so they intend to be clever and blur the image in just the right way to compensate for the optics of the eye. Unfortunately, this nice idea has no chance at all of working. The light passing through a lens must be specified by both its intensity and direction; the image on a display can control only the intensity. There is no pattern that can change the direction that light is emitted from a conventional display.

Or, some computer scientists were looking for a source of random numbers for cryptography, which depends for security on having a steady supply of random keys. They hit on the idea of aiming the camera connected to their computer at a 1960s lava lamp, and using the motion of the blobs as a source of randomness. In fact, a lava lamp is appealing to watch precisely because it is not completely random; there is a great deal of order in the motion. The electrical noise from a simple resistor is not only much easier to measure, it is one of the most random things that we know of. A far more convenient device can solve their problem far better.

One more computer scientist showed me the automated cart he developed for delivering mail. With great pride he turned it on and together we watched it crash into the wall. He was measuring the position of the cart by counting the revolutions of its wheels; if they slip at all it gets completely lost. I explained that there were techniques for measuring location inside a building, something like the GPS system used outside of a building. His instant response was, "Oh, that's hardware." It was the wrong level of description for him, so he was going to struggle on with software patches for a device that could never work reliably.

An education that forces people to specialize in hardware, or software, sends them out into the world with an erroneous impression that the two are easily separated. It is even embodied in our legal code, in the workings of the U.S. Patent Office. A patent must scrupulously distinguish between apparatus claims, on hardware, and method claims, on software. This means that "the medium is the message" is actually illegal: the message must be separated from the medium for patent protection.

The best patent examiners recognize that new technology is stretching the boundaries of old rules, and are flexible about interpreting them. The worst examiners refuse to accept that a single entity can simultaneously embody a physical apparatus and a logical method. I've spent years winding my way through the legal system with a particularly obtuse examiner who insists on trying to split an invention into its component hardware and software, even though the function of the device cannot be seen in either alone but arises only through their interaction.

Companies can't help but notice that these kinds of distinctions no longer make sense. I realized that we're living through a new industrial revolution when I saw how many senior executives visiting my lab said that they had no idea what business they were in. A newspaper company gathers and creates information, annotates and edits it, sells advertising, runs printing presses, and has a delivery fleet. As digital media make it possible to separate these functions, which of them are core competencies and which are legacy businesses? The answer is not clear, but the question certainly is.

One morning I met with a company that explained that they had reached the limit of complexity in what could be designed with a computer, and given the development cost of their product they needed better interfaces for designers to interact with large amounts of information. That afternoon a company explained that they had reached the limit of complexity in what could be designed with a computer, and given the development cost of their product they needed better interfaces for designers to interact with large amounts of information. The former made video games; the latter jet engines.

In the face of such rapid and uncertain change, a few lessons are emerging about how companies can respond. Instead of storing up large inventories of supplies and products, raw materials should arrive just in time to make products on demand. Management and computing should be done close to where the business happens, not in a central office. And production should be organized in flexible workgroups, not in regimented assembly lines or narrow departments.

Many of the same constraints apply to education, but few of these lessons have been learned. Universities go on filling students with an inventory of raw knowledge to be called on later; this is sensible if the world is changing slowly, but it is not. An alternative is just-in-time education, drawing on educational resources as needed in support of larger projects.

One of the best classes I ever taught at MIT was at one in the morning in Penn & Teller's warehouse in Las Vegas. We had gone out with a group of students to finish debugging the spirit chair prior to its first performance. In the middle of the night all of the hardware finally came together. Before the music could be tested, a computer had to combine the raw signals from the sensors to determine where the player's hands were. This is a classic data analysis problem. So I gave an impromptu lecture on function fitting to students who were eager (desperate, really) to learn it, and who then retained the ideas long after the performance was over.

The big new thing on campuses now is distance learning, using videoconferencing and videotapes to let people far from a place like MIT take classes there. This is an awful lot like mainframe computing, where there is a centralized learning processor to which remote learning peripherals get attached. Just like management or information processing, the most valuable learning is local. Far more interesting than letting people eavesdrop from a distance is providing them with tools to learn locally.

Some of this is happening naturally, as the Web lowers the threshold to make information widely available. More and more articles get shared through servers such as http://xxx.lanl.gov without needing to travel to research libraries to read expensive journals. Through the working notes my group puts on the Web, I discovered that we have virtual collaborators who use our results and provide thoughtful feedback long before the notes are formally published.

And some of this is happening through the tools. The same technology that lets us embed surprisingly sophisticated and flexible sensing and computing into children's toys or consumer appliances helps make the means for meaningful scientific experimentation much more widely accessible. A Lego set today can make measurements that were done only in specialized labs not too long ago.

Academics visiting the Media Lab usually start by asking what department we are in. They have a hard time understanding that the Media Lab is our academic home, not an appendage to another department. Uniquely at MIT, it both grants degrees and manages research. Learning and doing elsewhere are separated into departments and laboratories.

Military types visiting want to see an organizational chart, and are puzzled when we say that there isn't one. I spent a day with a Hollywood studio executive who kept asking who gets to green-light projects. He was completely perplexed when I told him that more often than not projects get initiated by the undergrads. Most every day I come to work knowing exactly what we should do next, and most every day they show me I'm wrong.

The reality is that there are many different ways to view the organization of the Media Lab, all correct: by projects, by disciplines, by levels of description, by industrial consortia, by people. It functions as an intellectual work group that can easily be reconfigured to tackle new problems. Once visitors understand this (lack of) structure, the next question they ask is how the Media Lab can be copied, and why there aren't more already.

In part, the answer is that it just requires getting these few organizational lessons right, but few institutions are willing to make that leap. We've had an unblemished record of failure in helping start spin-offs from the Media Lab elsewhere. What always happens is that when it comes time to open the new lab, whoever is paying for it expects to run it, choosing the projects and controlling the intellectual property. They're unwilling to let go of either, letting the research agenda trickle up from the grassroots, and eliminating intellectual property as any kind of barrier to collaboration.

In part, the answer is that there are a few unique features of the environment of the Media Lab that don't show up on any formal documents. To start, running the Media Lab is a bit like driving a bumper car at an amusement park. While we're more or less in control, the rest of MIT provides a great deal of enabling physical and intellectual infrastructure. This leads to steady jostling, but it would be impossible for the Media Lab to function in isolation outside of that less-visible institutional support.

Even that has a hidden piece. It was only after spending time at both Harvard and MIT that I realized that Cambridge has one university with two campuses, one for technology and one for humanities. While of course there are plenty of exceptions, broadly MIT's strength as a technology school frees Harvard from even trying to lead the world in bridge building, and because of Harvard's strengths MIT can be less concerned about Classics. Since MIT does not have a school of education, or a film school, there is not a turf battle over the Media Lab working on those things.

Then there are the students. It's not that they're any smarter than students elsewhere; it's that they're so desperate to make things work. I've never seen any group of people anywhere so willing to go without eating and sleeping to reduce something to practice. It almost doesn't even matter what it is.

One day I came in and found that my lab had been co-opted to make a grass display, a lawn mounted on mechanical pixels that could move to make an ambient agricultural information channel. The students building it labored heroically to make the drive circuits that could handle that much power, and fabricate the structure to merge the drive solenoids with the sod. The only thing they couldn't do is tell me why they were doing it. Once they realized that it was possible, they could not conceive of not making one.

About a month later I came in and found that my students had been up many nights in a row, hacking an interface into a global satellite system to get sensor data off the summit of Mount Everest for an expedition that Mike Hawley was putting together. They developed, debugged, and deployed a satellite terminal in a few days, slept for a few days, then went back to whatever else they had been doing. No one had ever been able to collect weather data from on top of Everest, since most people there are just trying to stay alive. The data from their probe went via satellite to the Media Lab, and from there it went to planetary scientists as well as to base camp to be relayed up to climbers on the mountain.

When the designer of the satellite link, Matt Reynolds, showed up in my lab as a freshman he was already the best radiofrequency engineer I'd ever met, including during my time as a technician at Bell Labs. This is a technical specialty that few people really master, and usually then only after a lifetime of experience. It's hard not to believe that Matt's knowledge is genetic, or comes from a past life. He as much as confirmed that one evening after we attended a conference in San Francisco, when we were happily sitting on a deck in Big Sur watching a memorable sunset. I casually asked him how he chose to come to MIT. The conversation ground to a halt; it was almost as if I had said something inappropriate. He paused, struggled to answer, and then said that he had known he was going to go to MIT since he was a fetus. He didn't choose to go to MIT, he had a calling to serve.

Another freshman, Edward Boyden, appeared one day with a ten-page manifesto for the future of all research. It was the most interesting nonsense I've read; he didn't have any of the details right, but the spirit and sensibility were wise far beyond his limited scientific experience. He came in with almost no relevant skills. I set him to work helping a grad student; in January Edward learned computer programming, in February he learned how to do 3D graphics and digital video, in March how to numerically model the behavior of electric fields, so that in April he could put all the pieces together and render the physics underlying the sensors we were developing to see with fields. Having caught up to the grad student, Ed’s only reaction was to be frustrated by his own slow pace.

It makes no sense to funnel that kind of raw problem-solving ability through a conventional curriculum. Edward learns too quickly, and is too intellectually omniverous, to be content following a prescribed path through knowledge. Matt spends a tiny fraction of each day taking care of the formal requirements of his classes, then gets back to learning things that go far beyond the classes. They arrived understanding a lesson that it usually takes students longer to learn: the goal of classes is to get you to not want to take classes. Once students know how to read the literature, and teach themselves, and find and learn from experts, then classes should take on a supporting role to help access unfamiliar areas.

One of the most meaningful moments in my life came in an airport lounge. I was waiting to fly back from my brother’s wedding, and ended up sitting with our family rabbi. In this informal setting, with time before the plane and no distractions, I screwed up my courage to say something that I had wanted to tell him for a long time. I explained that I found the morality, and history, and teachings of Judaism to be deeply significant, but that I had a hard time reciting formal rituals I didn’t believe in. He beamed, and said that the same was true for him. Letting me in on a secret, he told me that he saw many of the ceremonial aspects of Jewish observance as a formal scaffolding to engage people’s attention while the real meaning of the religion got conveyed around the edges. The formal structure was valuable, but as a means rather than an end.

Rather than start with the presumption that all students need most of their time filled with ritual observance, the organization of the Media Lab starts by putting them in interesting environments that bring together challenging problems and relevant tools, and then draws on more traditional classes to support that enterprise. The faster the world changes, the more precious traditional disciplines become as reliable guides into unfamiliar terrain, but the less relevant they are as axes to organize inquiry.