The Innovation Institute:
From Creative Inquiry Through Real-World Impact at MIT

by

Joost Paul Bonsen

S.B. Electrical Engineering & Computer Science, MIT, 1990

Submitted to the MIT Sloan School of Management in Partial Fulfillment of the Requirements for the Degree of

Master of Science in the Management of Technology

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Signature of Author: ______________________
MIT Sloan School of Management
May 12, 2006

Certified by: ______________________
Alex (Sandy) Pentland
Toshiba Professor of Media Arts and Sciences
Thesis Supervisor

Accepted by: ______________________
Stephen Sacca
Director, MIT Sloan Fellows Program in Innovation and Global Leadership

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Abstract

This document is an exploration into the past, present, and emerging future of MIT from the perspective of a participant-in and observer-of Institute life and learning, and seeks to better understand how creative inquiry at the Institute leads to real-world impact. We explore the Institute's history, mission, and creative ethos. We survey MIT's links to industry, highlight the inner-connections between the triad of research, education and extracurriculars, and explore the rich entrepreneurial ecosystem, how the Institute formally and informally educates and inspires new generations of founders, builders, and leaders. We conclude by observing how distributed initiative, inquiry, and leadership enable organizational reinvention and survey a few of MIT's emergent future frontiers.

Thesis Supervisor: Alex (Sandy) Pentland
Title: Toshiba Professor of Media Arts and Sciences

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If I did not mention you, I probably should have.

Introduction & Overview

MIT is one of the world's great epicenters of innovation and extraordinary impact. It is worth studying, documenting, and understanding better how creative work is organized, what happens on a daily basis, and its history and future outlook if only to improve upon the current state of affairs and perhaps to draw lessons worth sharing elsewhere. In any case, MIT is a fantastic and fascinating object of attention.

This document is an exploration into the past, present, and emerging future of MIT from the perspective of a participant-in and observer-of Institute life and learning, one affiliated with MIT for nearly (or merely) two decades as student, alumnus, employee, minion, volunteer, and often protagonist of new initiatives.

- **Part I** explores **Mens et Manus**, MIT's core mission, historic emergence, and creative ethos pervading the place.
- **Part II** surveys how MIT has been an historic Engine of the Innovation Economy by engaging industry, continually evolving, and maintaining **Real-World Relevance.**
- **Part III** looks at the rich interrelationship between the MIT Triad of Research, Education and Extracurriculars and how the Institute operates, at its best, to maximally **Orchestrate Innovation**
- **Part IV** explores the **MIT Entrepreneurial Ecosystem**, how the Institute formally and informally educates and inspires new generations of founders, builders, and leaders.
- **Part V** observes how distributed initiative and faculty-driven inquiry and leadership enable organizational reinvention and drive **Relentless Renewal**.
- **Part VI** surveys MIT's emergent **Future Frontiers**, research themes which cut across Institutional lines and exemplify new directions of inquiry.

This thesis attempts, therefore, to shed light on how **Creative Inquiry** leads to **Real-World Impact** at this remarkable **Innovation Institute**.

Part I

Mens et Manus:

the Core Mission, Historic Emergence, and Creative Ethos of MIT

MIT founder William Barton Rogers sought to prepare technical personnel for the challenges of the newly-industrializing, enlightenment society blossoming around him. With the support of far-sighted fellow Bostonians and other supporters, he persevered to found MIT in the mid 1800s as a place which would take a very practical, hands-on approach to learning and the arts. He envisioned training young men in ways relevant to their professional ambitions and the demands of business. Indeed, the founding charter emphasizes that MIT should pursue "practical application of science in connection with...commerce."[1]

Learning in the new Rogers polytechnical institution would be substantially by doing -- through actually making things -- a pedagogy today known as constructionism.[2] At the time, the dominant university mode in the US was that of received-learning represented by Harvard and its ivy-league.

Over the Institute's nearly 150 year lifespan, its overall mission has remained to perform excellent and enduring research and education for the maximum betterment of humanity.[3] Throughout this period, MIT has undergone many substantial shifts in the underlying strategic and tactical instantiations of this overarching mission, at times drawing closer to industry, then government, then back, all while starting new initiatives and even periodically restructuring itself rather dramatically.

Persistent throughout MIT's growth and emergence, however, has been a core creative ethos which pervades the place and has a tight hold certainly on students and faculty, but also staff and administration.

1.1 Creative Ethos Everywhere

MIT is an intense concentration of smart, ambitious, hard-working, and largely self-motivated individuals who collaborate with each other in thinking about and solving some of the world's biggest problems and most persistent challenges. People channel and apply themselves in many directions -- scientific discovery, engineering invention,

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[1] http://web.mit.edu/museum/fun/rogers.html
[2] http://en.wikipedia.org/wiki/Constructionist_learning
[3] Personal interpretation of the MIT Mission

authorship and the arts, humanistic inquiry, planning and design, entrepreneurial and business leadership, and more -- but everyone is united by a core creative ethos. MIT, at its best, weaves together the formal and informal, fun and work, the curricular and extracurricular, the lab and the pub, imagination and action. Certainly people live independent lives and have vacations and various degrees of connection to their work, but there is an all-pervading can-do ethos permeating the Institute that relentlessly seeks the new, the unknown, the better, the best, and beyond. MIT is an intensely passionate, striving place.

Learning-by-Doing -- MIT's motto Mens et Manus is Latin for Mind and Hand, representing thinking and doing. This summarizes the core essence of the MIT approach to learning. Rogers wanted his Institute to combine general, liberal education with practical, professionally relevant knowledge, to have ideas conveyed in the classroom actually practiced for real.

Lessons learned in a lecture are, therefore, practiced on paper via problem sets. And book-learning from the classroom and problem-sets are ultimately instantiated through projects where students actually build an integrated system.

For example, an MIT Mechanical Engineering student might learn all about engines in core classes and be asked to answer problem set or test questions about efficiency and heat transfer and fluid dynamics and the like. This is then complemented by building an actual working Stirling engine in the shop. And since MIT is a fairly competitive place, friendly but quite intense, each of the Stirling engines is put to a comparative test: whoevers rotates the fastest, wins.[4]

Similarly, MIT Electrical Engineering & Computer Science students learn about circuits, signals, programming, and more in core classes. Those lessons are then experience in the subsequent projects classes where students are expected to build ever larger and more sophisticated working systems out of a combination of hardware and software.

And MIT Sloan management students apply finance, marketing, and strategic analysis tools learned in core classes to project courses and ultimately in Action Labs, field experiences where they work in companies with executives on pressing business or organizational problems.

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[4] 2.670 Stirling Engine Spinoff http://web.mit.edu/2.670/www/spotlight_2006/

Creativity within Constraints -- Creativity is not unbridled or unbounded, however. Instead it is applied within constraints, where students are given tools, nurtured, encouraged, trained, given expectations, exposed to problems worth solving. Students come to appreciate a mix of fun and work, to value cleverness and elegance, to develop taste and judgment in assessing their own work and that of others.

Furthermore, while MIT certainly values and rewards individual performance by lone "superstars", students learn that creativity is not only a solo affair. Students come to see how collaboration, when appropriate, is tremendously powerful and invigorating. People learn by experience how to work with creative peers, how to seek out good talent, and figure out how to work together so that their combination is more productive and creative than they would be as separate individuals.

Highly Distributed Initiative -- MIT attracts and admits high-potential people as students, places them in a fantastic creative cauldron, spices it up with ideas and expectations, and ultimately leaves people alone to thrive or not. Especially in research projects or elective classes, students are given broad guidance and general expectations and then set free to creatively tackle the project. Similarly, many students have their own extracurricular project ideas which they pursue on their own initiative. These projects could be building a device, or running a club, or creating a conference, or performing a play, or the like. Accomplishing results is entirely up to the individual.

A culture of individual and distributed initiative pervades the Institute. Students are intensely forward-looking, and are interested largely in the cutting-edge or in solving some yet-unsolved problem. They also relish real-world relevance and usually find it uninspiring to be working on a boring problem with little larger potential, especially when there are real challenges world-wide that are more worth tackling.

Students are persistent and will not stop even when faced with seeming dead-ends or challenging odds. They have a show-me attitude towards their peers, talk alone is insufficient, they would like to see things prototyped and tried. And very early on, if not before they arrive at MIT, students embrace the notion that "it is better to seek forgiveness than to ask permission". Since most authority-figures are too busy, and most things students want to do are harmless, most of the time this outlook leads to a vibrant bubbling up of projects and activities. When things do go wrong -- as they can when students take too many risks or flirt with truly dangerous projects -- MIT has both the support systems necessary to minimize the damage and the general sensibility to turn otherwise negative episodes into learning experiences.

1.2 Campus as Creative Cauldron

Great ideas and activities emerge all the time in the MIT cauldron of creativity, far too many to properly acknowledge or give proper witness to. Nevertheless, a few examples might scratch the surface and serve to illustrate the vast richness and the MIT creative ethos incarnate.

Everyone is an Inventor at MIT... Including the Janitors -- After midnight at MIT, the Infinite Corridor buzzes with both night owl students and the custodial staff of the Department of Facilities. These late-shift folks not only keep the Institute clean, they also invent their way out of problems, just like anyone else, creating custom-padded mop handles, extra hooks, clever containers for cleaning fluids, and more. Portability, ergonomics, convenience, functionality, labor-savings -- all design criteria familiar to freshmen engineering students -- are also themes embraced by Institute custodians who have literally crafted solutions to their own specific problems.

Creative Hacks -- Hacks at MIT are not malicious viruses wreaking computer and network havoc. Instead the "Hack" is a prank, a clever joke or spoof or humorous prop or act. Usually done anonymously, and, at best, extraordinarily visible, great hacks are an art form at the Institute. The best are truly challenging to pull-off, putting the creative prowess of the hacker to the test and, in turn, being all the more inspiring to MIT's appreciative, technically-literate audience.[5]

Annual Engineers Amusement Park -- Every year at the end of Summer, residents at the East Campus dormitory create an inventorium of crazy build-it projects for both fun and to appeal to the newly arrived students at MIT. This ephemeral amusement park features student-engineered rides, exhibits, and toys entirely built out of scrap furniture, spare parts, and various raw materials. The construction occurs intensely in the few days leading up to the new student welcome week and is intended to attract new dorm mates as well as to simply inspire people.

How To Make (Almost) Anything Class Projects -- Every year, MIT Professor Neil Gershenfeld, director of the Center for Bits and Atoms, and his colleagues teach an elective project course where students learn how to use every tool in the machine shop

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[5] http://hacks.mit.edu/

and apply it to nearly every material in order to craft a wide range of components and devices. The end-project is chosen by the students themselves and can be nearly "anything".[6]

2.007 Intro to Design & Manufacturing -- As part of the 2.007 Introduction to Design & Manufacturing course, every Mechanical Engineering student gets a "Creativity Kit" -- an assemblage of raw parts, materials, motors -- and a playing field -- typically an obstacle course -- and a goal -- usually to capture or hit a target and to do so in competition with another contestant. These students build machines of their own design and compete like crazy. Plus they help each other. The instructors want students to learn by failing early and often, and then to advance forward by building upon this newly learned knowledge. Every student has the freedom to try something different and to deeply appreciate that failing after trying once is just an excuse to try again. Furthermore, they learn that ideas alone are insufficient and that, instead, a ceaseless interplay of ideas combined with execution in an iterative process is the real goal, one that is actually more of an outlook about the world: that everything can always be done differently and probably better.[7]

EnergyNight @ MIT Museum -- The MIT Museum hosts regular GradNights for graduate students, faculty, and friends to encourage informal networking. One example was the EnergyNight run in collaboration with the MIT Energy Club to showcase energy-related innovations and provoke cross-connections and conversations between people representing different disciplines and yet all interested in Energy as a unifying theme. With jazz background and light drinks and dinner, the ambience maximized interaction and even inspiration.[8]

IDEAS Competition Projects -- The annual MIT IDEAS Competition inspires dozens of student teams to build tangible prototypes of products which serve the needs of an all-too-often overlooked community. Sometimes the ideas emerge from class work, other times from research, and finally, many ideas result from extracurricular hobbies or time in the field working directly with a community in need. Most important, all the ideas are practical and relevant.[9]

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[6] http://www.media.mit.edu/physics/pedagogy/fab/
[7] http://pergatory.mit.edu/2.007/ and
http://web.mit.edu/smcs/inaugural/mit-2.007-history-04may2005-220k.asx
[8] http://web.mit.edu/mit_energy/EnergyNight/index.html
[9] http://web.mit.edu/ideas/www/index.htm

Shared Build-It Facilities -- MIT is like a sandbox and kit-of-parts and suite-of-tools all combined and available together. Anything that can be imagined -- and also does not violate the known laws of physics (and laws of economics) -- can be built. Many labs and departments have their own dedicated shops and equipment and computers and instrumentation, but several shared build-it facilities offer tools and support for making things. The Edgerton Shop opened in 1998 for free and open use to any MIT student.[10] Hobbyists interested in metal and woodworking use the MIT Hobby Shop.[11] Glassblowers and metal casters use the MIT Glass Lab.[12] Painters, ceramicists, and photographers use the Student Art Association studios.[13] The MIT Electronics Research Society (MITERS) has an enormous range of tools at its "student run EE lab, machine shop and staging area for large student projects."[14] Those interested in microfabrications will use the cleanroom facilities of the Microsystems Technology Lab (MTL).[15] Nanomechanics visit the transparent Nanolab on the Infinite Corridor.[16] Biologists needing microarray experimentation systems use the BioMicro Center.[17] Plus there are dozens of additional, more dedicated, special-purpose (and sometimes more limited-access) facilities campus-wide.[18] The essential creative openness of MIT, however, is that almost anyone can talk their way into using any tool or facility if they have a compelling reason, the prerequisite skills, and a reasonable demeanor.

1.3 The History, Emergence, and Growth of the Institute

In the 1860s, MIT founding President William Barton Rogers sought to pioneer a new type of institution, one where class work and fieldwork were both respected and academic ideas and real-world application. From temporary quarters to the original first building in Boston's Back Bay neighborhood, through a scattering of several building overflowing with people, to the current majestic location along the Charles Riverfront in Cambridge, MIT has both blossomed as an Institution and helped define the modern research university. This has all been made possible because of key decisions made by

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[10] http://web.mit.edu/newsoffice/1998/machineshop-0401.html & http://web.mit.edu/Edgerton/www/Shop.html
[11] http://web.mit.edu/campus-activities/hobbyshop/
[12] http://web.mit.edu/glasslab/
[13] http://web.mit.edu/saa/
[14] http://miters.mit.edu/
[15] http://mtlweb.mit.edu/services/fabrication/index.html
[16] http://web.mit.edu/nanolab/
[17] http://web.mit.edu/biomicro/
[18] http://fab.cba.mit.edu/tools_new/ & http://web.mit.edu/cmshop/

succeeding generations of MIT Presidents and trustees along with the distributed leadership of Institute faculty and increasingly MIT alumni.[19]

Founding Context of Boston and New England -- Rogers and his contemporaries lived in a vibrant, booming industrial revolution-era America and saw first-hand the growing need Boston firms had for qualified talent and inventive ideas.[20] Rogers proposed and persevered in ultimately founding a polytechnical institution along rather new lines, ones pioneered by only a few older schools[21] and rather opposite Harvard, Princeton, and others of the Ivy League.[22]

Pioneering New Kind of Polytechnic Institutions -- In recent years there has been an exponential growth in the number of MIT-style research universities founded worldwide as well as growth in capacity of existing universities. In China alone, the collegiate population has grown from a few million in 1990 to nearly 20M in 2006.[23] And yet when Rogers founded MIT, only Rensselaer (RPI) in the US, several Germanic institutions, and a few other nascent efforts in the US were role-models. He and colleagues created the Institute sui generis.[24] Peer school, RPI, was founded to foster "application of science to the common purposes of life"[25] by Rensselaer, the financier-founder.[26] Rogers founded the Institute in the same spirit.[27]

Succession, Stabilization, and Early MIT Growth -- In 1881, just before he passed away, President Rogers personally recruited the remarkable Francis Amasa Walker as his successor. Walker was able to raise additional moneys, to acquire more properties in Boston's Back Bay, and quadruple the size of MIT.[28] Under his tenure, the finances of the Institute stabilized and the first of various merger attempts with Harvard University was fended off. Curiously, Walker was an economist, not a scientist as Rogers had been. But as a quantitative social scientist, he represented a data-driven realist with practical experience and real-world connections. Walker had been field-promoted to general during the Civil War, had led the US Census for two decades, was co-founder of

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[19] http://libraries.mit.edu/archives/exhibits/wbr-visionary/index.html
[20] For a remarkably exhaustive survey of the pre-founding and early days of the Institute, see Stratton, et al Mind and Hand
[21] Such as Rensselaer Polytechnic Institute (RPI) -- http://www.rpi.edu/
[22] http://libraries.mit.edu/archives/exhibits/wbr-birthday/index.html
[23] http://news.com.com/2061-10796_3-5844915.html
[24] Killian
[25] http://www.rpi.edu/about/history.html
[26] http://www.rpi.edu/about/hof/vanrensselaer.html
[27] http://libraries.mit.edu/archives/exhibits/wbr-birthday/index.html
[28] http://libraries.mit.edu/archives/exhibits/maps/index.html#1905

the American Economics Association, and was author to the canonical economics textbook of that day.[29]

Walker's experience at the Census gave him a unique statistical handle on the technology-centered increasingly industrial economy of the period, and especially on the underlying entrepreneurial drivers of growth. He was one of the first scholars interested in entrepreneurs, viewing them as the crucial third element employing capital and organizing labor. Indeed, he viewed his personal mission at MIT as educating and inspiring a technologically-trained entrepreneurial class of people capable of changing the world. The alumni record shows that the men and women graduates from this period went on to become chief engineers, plant foremen, founders and leaders of companies, and creators of new disciplines in both academia and industry.[30]

A New Home for Technology -- By the time New Zealander Richard Maclaurin was recruited to lead the Institute in the early 1900s,[31] space was at a premium, Boston's Back Bay was largely full, and MIT needed a new home. President Maclaurin soon honed in on the still undeveloped landfill on the Cambridge shore of the Charles River, raised the moneys to purchase the land and to build upon it.[32]

This new home for Technology gave the institutions space for future growth.[33] Furthermore, for the first time MIT had enough (and wealthy enough) alumni who donated the moneys for Walker Memorial, the beginnings of a very powerful philanthropic feedback loop connecting alumni back with their alma mater.

Emergence as a Research University -- MIT President Karl Compton arrived in 1930 after an interregnum of short-term office-holders following the premature demise of President Maclaurin.[34] Compton, a physicist by training, initiated several structural reforms, including winding down several older, underperforming departments and creating the Schools structure at MIT. Whereas the sciences had been largely service departments supporting the education of engineers, Compton raised the status of the

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[29] http://libraries.mit.edu/archives/mithistory/biographies/walker.html
[30] Walker Biography
[31] http://libraries.mit.edu/archives/mithistory/biographies/maclaurin.html
[32] Prescott & new building book by Jarzombek
[33] http://libraries.mit.edu/archives/exhibits/maps/index.html#1916
[34] Hodgins & Killian

departments and bundled them together into a School of Science to parallel the Schools of Engineering and Architecture.[35]

During WWII, government-funded contract research volume skyrocketed thus giving valuable organizational experience to young administrators and setting the stage for the following several decades of remarkable growth, in expanded physical plant, in enrollment, and in faculty and staff, all largely fueled by government funding resulting from a combination of principled vision plus cold-war political urgency. MIT, along with peer institutions, combined a surging sponsored research agenda with education, increasingly of graduate students, thus forming the archetypal modern research university.

Polarized Around Science, Engineering, and the Arts -- MIT President James Killian lead the Institute in the vital post-WWII era when Federal financing of research became dominant, the newest MIT Schools of Management (Sloan) and Humanities, Arts, and Social Sciences (SHASS) were formalized, and MIT experienced its greatest growth ever in both absolute and percentage terms.[36]

Killian characterized MIT as "a university polarized around science, engineering, and the arts" which embraced the humanities while keeping a distinctive MIT approach to those vital disciplines.[37] The "T" in MIT is thus Technology in its broadest possible sense, one embedded in the root etymology of the term "tekhnologi, the systematic treatment of an art or craft."[38]

While the dominant visible thrust of research and activity at the Institute could be characterized as classic hard-core science and engineering, the humanities, arts, and basic through applied social sciences are fully one third of total faculty headcount, research volume, and represent three of five Schools. The essential fact that President Killian captured in his turn of phrase is that all disciplines are pursued in an essentially-MIT way, with rigor, methodological sophistication, and using (often inventing) the latest tools and techniques.

Campus is a Small City -- The MIT physical campus today is like a small city with nearly 170 mostly contiguous acres along the northern shore of the Charles River basin

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[35] http://libraries.mit.edu/archives/mithistory/biographies/compton.html
[36] http://web.mit.edu/ir/pop/index.html
[37] Killian autobiography
[38] http://dictionary.reference.com/search?q=technology

in Cambridge, Massachusetts.[39] The campus is physically long, stretching some two kilometers from east to west. Most of the living groups and athletic facilities are on the western half and labs and classrooms on the eastern half with the resident population migration back and forth.

The 24 by 7 population of resident students and faculty and those staff on night duty is some 6,000 and the peak daytime population over 20,000. The Institute has a dedicated police force, transportation service, power plant, planning organization and more. With rare exceptions, the Institute is a 24 hour per day, 365 days per year operation. Indeed, lore has it that there is always at least one light on -- i.e. one person working -- in the Green Building, the tallest on campus, and this is an informal indicator of the relentless work-ethic of the place.

Architecting for Innovation -- Physical space is a tremendously influential driver or impediment to intellectual connection-making. At worst, the buildings, rooms, halls are dreadful. Usually, they are merely functional, like staple foods without spice. At best, however, key spaces on campus are an inspiration, multiply-purposed, and wonderfully frothy with serendipitous side-effects.

The Main Group of buildings, the original central core of MIT, is a stellar example of such architecture. In his recent book, Designing MIT: Bosworth's New Tech, Mark Jarzombek delves deeply into the design tensions between architect Welles Bosworth and engineer John Freeman whose competing visions for the new campus clashed and ultimately lead to a design that, somewhat surprisingly, was not a committee compromise but rather an inspiration, featuring plentiful natural lighting, tall-ceiling spaciousness, maximum reconfigurability, safe long sight-lines, wide corridors, and broad, open stairwells.

While a matter of some controversy, it is regrettable that these early buildings set the high-water mark for clean lines, upgradeability, and enduring livability. Subsequent designs on campus have too often been less generous of line, low-slung and vaguely dungeon-like, made of lesser, often brutally minimal materials, and, especially recently, have failed to deliver in physical form anything near the high-minded principles promised by the architects.[40]

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[39] http://web.mit.edu/facts/campus.shtml
[40] http://web.mit.edu/evolving/about/overview.html

1.4 Core Mission

The basic goal of the Institute is connecting creative inquiry with real-world impact, an aspiration which has been captured in various ways by Presidents and other Institute leadership. The annual MIT Facts formally states it as:

> **The mission of MIT is to advance knowledge and educate students in science, technology, and other areas of scholarship that will best serve the nation and the world in the 21st century.**[41]

President Compton commissioned Lobby 7 to include carved in stone at the main entrance to MIT:

> **Established for Advancement and Development of Science its Application to Industry the Arts Agriculture and Commerce.**[42]

In her 2005 inauguration and more recent addresses, President Hockfield has distilled what she sees as three core values pervading MIT:

1. **Integrating Teaching and Research** -- the tight interconnection between learning and doing, emphasizing that everyone, including senior faculty and deep researchers also play a role in education, and that the combination leads to intense creative inquiry.
2. **An Unwavering Passion for Excellence** -- MIT is a place with high standards and keeps raising them. This requires being selective and having integrity and honesty in self-assessment and relentlessness in self-improvement.
3. **Bringing Knowledge to Bear on World's Great Challenges** -- the work done at MIT must have relevance on the problems facing humanity, creative inquiry must lead to real-world results, and that this is a moral responsibility all at the Institute should willingly shoulder.

The core principles pervading MIT have been articulated and built-up over time, first by Rogers and the early Institute faculty and leadership, and more recently in periodic rethinks where MIT charges a committee of scholars -- largely faculty but usually including some student input -- with stepping back from the issues of the day and

[41] http://web.mit.edu/mission.html
[42] http://hacks.mit.edu/Hacks/by_year/1994/entertainment_and_hacking/

assessing if there are gaps in the MIT suite of activities and to articulate the core principles of the place anew.

It is regrettably easy to pay lip-service to high-minded principles. Sometimes they are bandied about so frequently people forget they actually have deep relevance. Furthermore, mission-statements are usually so abstract and so "generally good" that no one can argue with them, but no one can use them for practical guidance either.

The challenge, of course, is to connect everyday action with these overarching principles. Even then reasonable people can disagree. But if one has the discipline to connect the dots, to link a proposed course of action logically to higher-level strategies and ultimately to the global mission, then at least one boosts the odds that the course chosen is sound, and that others can understand the decision.

Most of what frustrates students or anyone in a larger organization results from disconnection between stated aims and tangible actions. Perhaps there is a connection, but simply difficult to perceive. Or perhaps some kind of failure mode is at work. For instance, if two parts of a larger organization are working at cross-purposes. Or if one part of an organization is dominated by short-term thinking, and thus not paying attention to the longer-term implications. Or if the decision-maker only cares about the direct, first-order consequences of a decision and neglects the second- and third-order impacts. All these failure modes and more especially persist in the absence of systematic review and deep embrace of the MIT core principles and founding mission.

The late 1990s Task Force on Student Life and Learning was one of MIT's most recent comprehensive reviews of the educational mission of the Institute and the way MIT actually operates.[43] The resulting report advocated several new and renewed emphases on extracurricular community and integrating the formal and informal sides of the MIT experience. This sort of review, of overarching Institute action as well as more focused elements, is a central and necessary part of "pursuing excellence", and is a mode of Institutional self-assessment wherein MIT as a whole also Learns-by-Doing.

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[43] http://web.mit.edu/committees/sll/

Part II

Real-World Relevance:

MIT as Engine of the Innovation Economy

MIT has been tightly linked to the practical needs of society and industry since its foundation in the 1860s. The outflow of the Institute are people and ideas which have long stoked what today is called the "Innovation Economy."[44]

Faculty and alumni have gone on to found thousands of companies worldwide, started or lead dozens of universities, pioneer entirely new industries, run major civic and non-profit entities, and most generally, serve as inventive scientific, engineering, and other creative talent in organizations distributed across the globe.

This is a very self-reinforcing process, with MIT both driving and participating in, and ultimately benefiting from tight engagement in a larger innovation ecosystem. Especially interesting (although a relatively small fraction of MIT's total outflow of people) are those who found, build, and lead new ventures. These entrepreneurs are supported by a rich entrepreneurial ecosystem at MIT, which fosters, encourages and supports new venture creation and development.

2.1 Long-Time Engagement with Industry and Society

MIT has long pioneered practical industrial-academic interactions. This ethos was embedded in the founding principles of President Rogers "advancing the practical arts" in 1865,[45] and practiced by Professor Cross helping Bell invent the telephone in the 1870s,[46] President Walker's research and teachings on entrepreneurship in the 1880s, alumnus Arthur D. Little's support for sponsored research in Applied Chemistry in the early 1900s, President Maclaurin's industrial sponsorship initiative The Technology Plan in 1918, Professor Bush's formulation of the first Institute Patent Policy in 1932, President Compton's invention of venture capital with American Research & Development in 1946,[47] President Killians initiation of the Industrial Liaison Program in 1948[48] and the Tech Square urban renewal project in 1959, IBM's US$13M license of

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[44] http://www.mtpc.org/ & http://mitworld.mit.edu/video/108/
[45] http://web.mit.edu/museum/fun/rogers.html
[46] http://web.mit.edu/museum/fun/cross.html
[47] Killian p.379-381
[48] http://libraries.mit.edu/archives/histories/ilp.html

Professor Forrester's MIT-owned core memory patents in the 1960s,[49] and much more by many others. Each of these Institutional initiatives was driven by the opportunities and pressures of the time.

The challenge to come remains, as President Killian speculated, that "new, and yet to be conceived, arrangements must be invented to take full advantage of the university-industrial connection."[50]

2.2 Pioneering Industry Connections

Active Faculty Consulting and Collaborations with Industry -- From as early as the lean-budget years under President Rogers, MIT faculty have had outside consulting arrangements with industry. In the 1870s, Physics Professors Pickering and then Cross helped a young Alexander Graham Bell in research essential to the development of the telephone.[51] In the 1890s, Professor Samuel Prescott helped Lyman Underwood, of the canning family, prevent food spoilage.[52] This knowledge allowed MIT alumnus John Dorrance to build the great Campbells Soup company.[53] Many faculty and Institute officers have served on the boards of major industrial organizations, for example, Presidents Compton and Killian on the GM board.[54] Since the 1930s, MIT has formally acknowledged, and even encouraged, that professors work roughly one day per week on outside professional activities. Today the vast majority of professors have some kind of consulting connection with organizations beyond MIT.

Formal Institute Liaison with Industry[55] -- In addition to the individual professional connection by many faculty with industrial concerns, MIT was the first university to start a formal and systematic liaison with firms. President Maclaurin first attempted this with his Technology Plan in 1918, under which MIT signed up nearly 200 companies for fees totaling some US$1 million. But Maclaurin's untimely death and as-yet unresolved difficulties forced his successors to largely abandon the Plan. It did result, however, in the formation of the Institute's Division of Industrial Cooperation, now known as the Office of Sponsored Programs. After WWII, at the urging of alumni industrialists,

49 Rescuing Prometheus p.37
50 Killian p.257
51 http://web.mit.edu/museum/fun/cross.html
52 http://libraries.mit.edu/archives/histories/bio.html & http://web.mit.edu/newsoffice/tt/1993/may19/31230.html
53 http://web.mit.edu/newsoffice/founders
54 Killian p.294
55 Killian p256, MIT: Shaping the Future p163

President Killian revisited the idea of a formal connection with big business and started the Industrial Liaison Program (ILP) in 1948. This then-novel means of resource development and knowledge transfer was later adopted by numerous peer institutions. More recently, MIT has broken new ground with large-scale multi-year research contracts with industry, including centers, for instance the Media Lab, largely supported by corporate sponsorship.

Pioneers of Industrial Research[56] -- Early MIT alums and faculty played a formative role in the creation of the modern industrial research organization in the United States. Graduate Arthur D. Little started his firm in 1886, the first management and research consultancy in the US. In the early 1900s, alumnus Frank Lovejoy became trusted technical assistant to George Eastman, founder of Eastman-Kodak and later one of MIT's most generous philanthropic investors. Alumnus and Professor Willis Whitney took part-time leave from MIT to build and run the GE Research Laboratory. Alumnus Frank Jewett founded and ran Bell Laboratories. These men and their successors literally invented the business of R&D.[57]

Genesis of the Venture Capital Industry -- After WWII, MIT President Compton sought new avenues to transfer technologies out of the lab for the practical benefit of humanity. Towards this goal, Compton, Senator Flanders of Vermont, a couple MIT department heads, the Institute Treasurer, and HBS Professor Georges Doriot founded the first formal venture capital fund, American Research & Development (ARD). This pioneering fund invested in many firms, but is most famous for its US$70,000 investment in Professor Jay Forrester's former graduate students, Ken Olsen and Harlan Anderson, and their firm, Digital Equipment Corporation (DEC). Literally dozens of venture capitalists learned their trade as assistants to or students of Professor Doriot and ARD, thus spawning a new sector of the financial industry.[58]

Early Pacesetter in Continuing Education -- MIT pioneered the continuing education of technological executives. Prompted by donations from alumnus Alfred P. Sloan, the Institute created the Sloan Fellows Program in 1938 for advanced business study. Later in life, Mr Sloan prompted the founding of the Center for Advanced Engineering Studies in 1963, initially an effort to bring mid-career engineers back to MIT, now the Center for Advanced Educational Services, part of the Institute's initiative to use the latest

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[56] Killian p.259-260
[57] History surveyed very nicely by Buderi in Engines of Tomorrow
[58] Surveyed by Roberts in Entrepreneurs in High Technology & Killian p.379-381

"technologies to distribute MIT's educational offerings -- both current and future -- beyond the Cambridge campus."[59]

Founders of New Educational Institutions -- While not strictly a connection with Industry, MIT's substantial role in founding several new technology institutions worldwide is a notable example of transferring "organizational" technology and "educational" know-how. MIT President Francis Amasa Walker played a key role in founding Stanford in the 1890s.[60] More recently, Churchill College, a technology school founded in 1958 at Cambridge, UK, was partly inspired by Churchill's visit to MIT for the mid-century convocation.[61] The Birla Institute of Technology and Science (BITS), founded in 1966, was seeded by MIT alumnus G. D. Birla and built with help from Institute officials, including Professor Bartlett and President Killian. And in the same period, the Indian Institutes of Technology (IITs) were formed in consultation with MIT Professor Dahl and others from peer institutions.[62]

Regional Economic Development and Urban Renewal -- MIT played a key property development role in creating a vibrant technology venture zone around the Institute. After MIT came to Cambridge in 1916, Memorial Drive towards Kendall Square became known as "Research Row", having attracted companies like Arthur D Little and National Research Corporation.[63] In 1959, MIT catalyzed and financed the Technology Square urban renewal project near Kendall Square in cooperation with the Cambridge Redevelopment Authority and Cabot, Cabot, and Forbes.[64] In the early 1980s, MIT was instrumental in securing the financing for the Cambridge Center, built on land owned by Cambridge and developed by Boston Properties.[65] Most recently in the 1990s, MIT's University Park, built on the MIT-owned former Simplex property in collaboration with independent, for-profit Forest City Development, has reinvigorated the neighborhood between MIT and Central Square and has been landlord to dozens of MIT-related startup companies.

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[59] http://caes.mit.edu/About
[60] See Walker Bio & Prescott's When MIT Was "Boston Tech" & http://www.stanford.edu/home/stanford/history/begin.html
[61] Killian p.113
[62] Killian p.370
[63] Roberts p.37 & Killian p.374
[64] Killian p.374
[65] Personal interview with former MIT planner Bob Kahner June1, 2000

2.3 Historic Modes of Systematic Technology Transfer to Industry

Prominent Alumni Industrialists[66] -- The most prominent product of MIT has been and remains the graduating student body. These alumni end up inventing and innovating new technologies, discovering new knowledge, and founding and building new organizations, both for- and non-profit. Arthur D. Little, Cabot of Cabot carbon black, numerous du Pont's, both Stone & Webster, both McDonnell & Douglas, Hewlett of HP, Koch of Koch Industries, Noyce of Intel, Metcalfe of 3Com, Swanson of Genentech, Nickerson of Gilette, Stata of Analog Devices, Champy of Index Systems, and literally thousands more all graduated from MIT and founded companies. Notable historical business leaders include alumnus Alfred P. Sloan, long-time CEO and builder of General Motors and his classmate, Gerard Swope, long-time CEO of General Electric. Both, incidentally, played crucial roles on MIT's Corporation as trustees and generous philanthropic investors in MIT's educational endeavors.

Faculty-Founded Companies -- MIT faculty have founded companies from the very earliest days of the Institute, very often participating as partners in consultancies, such as Electrical Engineering Professors Jackson and Moreland. Interim MIT President Elihu Thomson was co-founder of what became General Electric;[67] Professor Vannevar Bush co-founded Raytheon in the 1910s; Doc Edgerton co-founded EG&G in 1931 with two graduate students; Professors Bolt, Beranek, and Newman founded BBN in 1948; Professor George Hatsopoulos founded ThermoElectron, and left MIT to pursue this full-time; Professor Amar Bose founded BOSE Corporation, and many more.[68] Professor Greg Yurek founded American Superconductor in the late 1980s and also left his tenured position at MIT to lead the firm.[69] The faculty founder phenomenon has oscillated over time, with some years witnessing a boom in faculty startups (and equally hyperbolic press coverage) and other times rather less.

Long-Time Encouragement of Entrepreneurship -- Entrepreneurship has been studied and taught at MIT since the 1880-90s when President Walker highlighted the crucial role of entrepreneurs in both his writings and required undergraduate class on Political Economy.[70] Most encouragement towards entrepreneurship occurred

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[66] Killian p.259 & http://web.mit.edu/newsoffice/founders
[67] Killian p.259
[68] Roberts p.4-6
[69] http://www.amsuper.com/aboutus/management_team.cfm
[70] Walker biography & http://cepa.newschool.edu/het/profiles/walker.htm

informally, from faculty peer-to-peer or with their students. Formal entrepreneurship education began with MIT alumnus Richard Morse, founder of National Research Corporation (creators of MinuteMaid frozen orange juice concentrate), who returned to MIT in 1956 and started New Enterprises, the MIT Sloan class on preparing business plans.[71] Morse later ran the MIT Development Foundation in the 1970s, a first attempt to systematically invest in MIT-related startups with the returns benefiting the Institute.[72] Professor Ed Roberts collaborated with the MIT Alumni Association in the late 1960s to run Seminars on entrepreneurship around the US.[73] Demand was so high they soon formed a Venture Club in New York City and ultimately the MIT Enterprise Forum with chapters throughout the US and increasingly overseas.[74] Since the mid-1980s, the MIT Technology Licensing Office has pro-actively encouraged new startups. And, as explored more fully in a subsequent section on the MIT Entrepreneurial Ecosystem, there exists today a rich web of formal and informal support mechanisms for MIT-related new venture development.

2.4 Intellectual Property (IP) and Outside Consulting Policies

Pioneering Technology Licensing -- By traditional metrics of performance, MIT has been a pioneer in the capture and commercialization of Intellectual Property (IP).[75] The MIT Technology Licensing Office (TLO), along with the Patent Counsel, and Office of Sponsored Programs (OSP), are responsible for the everyday administration of MIT's IP policies. As part of the process, technology licensing officers work with MIT inventors, decide what to protect, do so with outside patent attorneys, seek potential licensors, and ultimately negotiate the actual license agreement. Each officer focuses on a technical domain and manages an IP portfolio of inventions and licenses in that domain.[76] The overall TLO process leads to hundreds of inventions per year, upwards of a hundred granted patents, and dozens of licenses to both established and startup firms.[77]

Current MIT IP Policies -- Current MIT policies on patents, copyrights, and commercialization (or IP) were largely formulated in 1985-87 by the Bowen Committee

[71] Story relayed by MIT Entrepreneurship Center Managing Director Ken Morse and Chairman Ed Roberts
[72] Based on interview with former MIT Treasurer Glenn Strehle
[73] Robert p.42
[74] Based on comments by former Forum director Ed Dunn
[75] c.f. http://web.mit.edu/newsoffice/1999/patents-0113.html
[76] MIT TLO website http://web.mit.edu/tlo/www
[77] http://web.mit.edu/tlo/www/pubs.html

and are contained in the Guide to the Ownership, Distribution, and Commercial Development of MIT Technology.[78] At that time the former MIT Patents Office was revamped and turned into the TLO, with the assistance of visiting Stanford director of technology licensing, Neils Reimer. The new TLO was largely staffed by experienced scientific and technological people, such as current director Lita Nelsen, and former director John Preston, who oriented the office towards the licensing and transfer of technology, rather than merely the formal patenting and protection of inventions.[79] This technology transfer mentality was largely inspired by the Bayh-Dole act of 1980 which not only granted universities ownership of IP resulting from government sponsored research, but mandated the commercialization of this IP and, in turn, that the individual IP inventors also receive direct compensation for their role.[80]

History of IP Policy[81] -- MIT has long considered and formulated policies governing faculty connection with industry and the commercialization of useful inventions. MIT's original patent policy dates back to 1932 when Professor Vannevar Bush considered the matter and formulated a written statement. Prior to this formalization, MIT let the matter of patenting remain entirely at the discretion of the individual faculty, and to their personal reward, much like the current policy on copyrighted textbooks and most other publications. In 1937, MIT elected to use an outside agency, the non-profit Research Corporation, as its technology licensing organization. Research Corporation was seen as a way for MIT and a handful of peer universities to combine their efforts at licensing, and to "outsource", to use modern parlance, while staying somewhat removed from the legal and tax implications and public relations risks of aggressive licensing run in-house. At that time, a few non-profit institutions were coming under governmental scrutiny for allegedly having exercised too strong "monopoly" control over their patents, a fear which diminished after WWII.

Policy Updates -- WWII lead to a surge in patentable inventions at the Institute. While almost all of the work in MIT's Radiation Lab was performed under the so-called Short form government contract, some 400 additional contracts with MIT were Long form. Short form reserved all patent rights to the government, while Long allowed MIT to

[78] http://web.mit.edu/tlo/www/guide.toc.html
[79] History based on informal interviews with Professor David Litster, former MIT VP for Research and Chair of the then Committee on Copyrights and Patents
[80] http://www.sciencemag.org/cgi/content/full/279/5356/1460
[81] History partly drawn from MIT President Killian's biography p.133-140 & McKusick's "Study of Patent Policies in Educational Institutions, Giving Specific Attention to MIT", 1948

manage its own patents.[82] Motivated by this surge of activity and increasing pressures on faculty to spend more time away from MIT on independent projects, President James Killian in 1953 appointed the Soderberg Committee to comprehensively review MIT policies on outside consulting and patents management. This Committee and other more modest ones of lesser scope considered and refined the relevant policies throughout the 1960s and 1970s. These patent policies served MIT well for many years and, for example, were an instrumental force in securing the multi-million dollar IBM settlement over rights to Professor Forrester's magnetic core memory for digital computers in the 1950s and 1960s. What differentiates the modern era is the sheer volume of and the revitalized and proactive bent of the TLO towards technology transfer, a process which is not without some friction. MIT continues to review IP policies and a standing committee chaired by the MIT VP Research provides oversight.[83]

2.5 Non-Profit and Structural Spin-offs

In addition to the individual activities of faculty and alumni, and a surge of formal licensing volume, MIT has employed structural spin-offs where entire project teams, groups, Labs, or Centers are transferred or spun out as coherent entities, mostly in the non-profit sector, but typically motivated by a desire for greater independence and connection with industry. These are relatively rare, but especially interesting in that they allow the Institute to both scale-up its non-profit influence, and to do so "off-book", freeing up space and resources for the next new thing on campus.

MITRE Corporation -- MITRE is a non-profit formed in 1958 from MIT Lincoln Lab's Division 6 to handle system integration work on air defense projects. Today this research and development contracting organization employs over 5,600 people working on several hundred distinct technical projects.[84]

Education Development Center (EDC) -- In 1958, in the post-Sputnik era, MIT embarked on the Physical Science Study Committee (PSSC) high school education reform initiative lead by Professor Jerrold Zacharias. This Educational Development Center was spun out of MIT and is now the non-profit Newton-based Education

[82] McKusick p.275
[83] http://web.mit.edu/committees/ip/policies.html
[84] http://www.mitre.org/about/index.html

Development Center (EDC) which employs some 1,100 people worldwide with activities in some 60 countries.[85]

Draper Labs -- The Charles Stark Draper Labs were originally the MIT Instrumentation Labs and spun out in 1973 during the height of anti-Vietnam war protests. The founding focus on precision guidance, navigation, and control work has continued as have new research thrusts in the direction of special operations in environmentally hazardous conditions and biomedical diagnostics and systems engineering. Today the lab employs over 1,000 largely at headquarters near MIT in Kendall Square.[86]

Society for Organizational Learning (SoL) -- The Society for Organizational Learning began in 1991 as the Organizational Learning Center at the MIT Sloan School of Management and was spun out in 1995-7 with the goal of expanding its corporate and civic learning community and concentrating on theory development, publications, conferences and the all-embracing theme of global sustainability through business innovation.[87]

One Laptop Per Child (OLPC) -- MIT Media Lab founder Nicholas Negroponte and lab colleagues have recently in early 2006 created a non-profit association to further develop the $100 Laptop, an educational initiative intended to change the lives of children everywhere.[88]

2.6 Outflows from the MIT "Innovation Pipeline"

If one steps back from the complex details of the research and educational endeavors at MIT, one can pop up a few levels of abstraction and characterize the flow of talent and ideas as a Pipeline flowing from sources -- new people and ideas bubbling up in labs -- through various phases of instantiation, recombination, and refinement (as well as failure, rejection, and abandonment) and ultimately moving on, exiting the boundaries of the Institute.

The MIT outflow comes in a few dominant forms, including New Knowledge, Educated People, Organizational Spinouts, and more General Influences.

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[85] Killian p.402 & http://main.edc.org/ See also Karen Worth's comments at Philip Morrison's memorial service -- http://www.memoriesofmorrison.org/MITMemorialCelebration--September102005.html

[86] http://www.draper.com/corporate/history/history.htm & http://www.draper.com/corporate/profile/profile.htm

[87] http://www.solonline.org/

[88] http://www.laptop.org/ & http://laptop.media.mit.edu/ & http://www.media.mit.edu/windup/

Knowledge -- Knowledge products emerge in various forms from MIT:

- **Scholarly Works** -- the most basic and central to the scholarly mission of the place are contributions to the vast accumulating body of human knowledge, usually in the form of journal articles, conference talks, and the like.
- **Educational Tracts** -- disciplines emerge over time as scholars and practitioners in a field formalize and systematize the essentials out of what was before an often messy, inconsistent mélange of methods, nomenclature, and incomplete early results. The most tangible result are core texts, the defining documents allowing others to learn and also embrace the discipline.
- **Popular Awareness** -- many if not most scholar believe education should be both available and accessible for all and therefore publish books and articles of a more popular and generally informative nature.
- **Patents** -- In the US and worldwide, the legal form of exerting priority in having created new products, methods, or processes is the Patent.
- **Accessible Everywhere** -- New modes of communication and sharing have made MIT available to all, instantaneously.

Talks & Publications -- All thousand faculty at MIT regularly publish in their respective scholarly journals. The most prolific Professors, for instance Richard Wurtman[89] and Bob Langer,[90] have been authors or co-authors of nearly a thousand papers.

Patents -- Patents are granted by the US and international governmental bodies to inventors in exchange for publicly disclosing essential details of their novel and non-obvious invention. The MIT Technology Licensing Office received over 500 invention disclosures from MIT-related people in 2005. They filed US patent applications on over 300 of these disclosures. And in 2005, the US granted MIT over 130 patents (since the review process can take one or more years, there is a pipeline effect: a subset of the 300 2005 filings will likely be granted as patents between 2006-2008)[91]

Publishing -- In addition to the scholarly journal publications, conference talks, and patent declarations, MIT has several channels for sharing more general or popular knowledge with the world. Technology Review (TR) began in 1899 as an alumni

[89] http://wurtmanlab.mit.edu/publications.php
[90] http://web.mit.edu/langerlab/langer.html
[91] Data from Steve Brown and TLO annual statistics http://web.mit.edu/tlo/www/fy05.html

newsletter connecting graduates with happenings at the Institute and advances in technology. During the 1970s, TR received growing interest beyond alumni circles and in the 1990s, MIT recast the magazine as the centerpiece of an independent media company helping "business and technology leaders... in shaping markets and driving the global economy."[92] With nearly a quarter-million subscribers of US and international editions, TR influences millions of key decision-makers and technologists. One-time TR editor (and later President of MIT) Jim Killian went on to create The Technology Press, today known as the MIT Press (MITP) to disseminate especially scientific, architectural, economic, and technical knowledge. The MITP publishes several hundred new books per year and several dozen journals as well.[93] TR has a more focused counterpart in Sloan Management Review (SMR), a reviewed journal of applied management articles especially oriented towards the thoughtful business leader. MITP collaborates with SMR to publish a series on Strategy and Innovation [94]

People -- Talent flows into MIT as students, faculty, and staff. A few stay at the Institute for the rest of their professional careers (the so-called "lifers"). The majority, however, move on to play productive roles in other organizations. The bulk of MIT's outflow are, of course, students, some two thousand graduating per year, leading to a accumulative total of some 100,000 living alumni are today spread worldwide.[95] Nearly half of the almost 1,000 undergraduates continued on for further graduate studies, most often at MIT.[96]

Startups -- MIT is an oasis of excellence in thought and action and attracts people who are -- or will become -- prolific creators of wealth. As technology inventors and founders, builders, and leaders of companies, MIT students, faculty, staff, and alumni/ae create and sell products and services which benefit themselves and the world at large. Such Institute-related entrepreneurial ventures have several root-sources:

- One or two dozen per year are formally licensed through MIT's Technology Licensing Office (TLO).

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[92] http://www.techreview.com/corp/about.aspx
[93] http://mitpress.mit.edu/
[94] http://sloanreview.mit.edu/smr/book/
[95] http://web.mit.edu/facts/alum.shtml http://web.mit.edu/facts/geographic.shtml
[96] MIT Facts http://web.mit.edu/facts/

- Perhaps as many as 80% of the faculty also consult on their own account, often creating an engineering or design proprietorship or partnership as their working vehicle.[97]
- Some faculty found scalable high-technology, venture-backed ventures but do so without apparent use of MIT-owned technology.
- Students and young alumni typically do not found firms while at or soon after MIT, but there are, at least, 5 to 10 exceptions to this rule every year, including many who proposed their ideas or business plan through MIT's invention and entrepreneurship competitions.
- Approximately 150-200 firms are founded annually by alumni who have left MIT.[98]

MIT $100K Entrepreneurship Competition Venturing -- Since 1989, over 1,500 teams of nearly 5,000 MIT students, alumni, and friends have participated in what is today known as the MIT $100K Entrepreneurship Competition. The founding and operations of this Competition are described in greater detail in the upcoming section on the MIT Entrepreneurial Ecosystem, but especially interesting here is the substantial practical startup consequences of this endeavor: Since its founding, alumni participants in the Competition have gone on to found over 80 companies with, depending on market conditions, aggregate value of some US$5-10 billion dollars. These firms collectively employ an estimated two thousand people and received at least US$200M in venture capital financing.[99]

Alumni Startups -- The MIT family has a rich history of entrepreneurship. A study prepared by the Bank of Boston in 1989 found 636 firms in Massachusetts founded by MIT alumni employing more than 200,000 with aggregate world-wide sales of nearly $40 billion. In 1990, a study released by the Chase Manhattan Bank found 176 existing MIT-founded companies in the Silicon Valley area employing more than 100,000 with aggregate sales topping $20 billion. The MIT: Impact of Innovation study published by BankBoston in 1997 reported that over 4,000 firms had been founded by MIT-related people worldwide, employing over one million people and with nearly a quarter-trillion dollars in aggregate annual revenues.

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[97] Personal guesstimate
[98] See MIT: Impact of Innovation http://web.mit.edu/newsoffice/founders/
[99] http://www.mit50k.net/about/

For example, corporate titans such as Amgen, AMP, Campbell Soup, Genentech, Hewlett-Packard, Intel, McDonnell Douglas, National Semiconductor, Rockwell International, Tandem, Teledyne, Texas Instruments, Tyco International, and 3Com -- all multi-billion dollar public companies, some now merged into other firms -- were each co-founded by MIT alumni. Massachusetts-based concerns such as DEC, Gillette, Raytheon, ThermoElectron, EMC, EG&G, IDG, Lotus Development, Analog Devices, Teradyne, Bose, Computervision, Dynatech, M/A-Com, Arthur D. Little, PictureTel, Haemonetics, Ionics, SatCon Technology, PerSeptive Biosystems, Powersoft, Atria Software and Avid were each co-founded by MIT alumni.

And these are only the most well-known companies. Hundreds, if not thousands, of MIT alumni, faculty, staff, and current students have started and built their own firms and dozens, if not hundreds, more are in the labs and classrooms at MIT right now.

Global & Cultural Influence -- Universities worldwide look to MIT as a pace-setter. Many institutions were inspired-by and in several cases closely emulated MIT in organization and intent. Student-run business plan competition runs a conference for the organizers of other business plan competitions, thus replicating (or encouraging replication of) a powerful piece of institutional support for entrepreneurship.

MIT is also an advocate for national policy awareness and sensibility. Through big studies, behind-the-scenes lobbying, bold initiatives, and walking-the-talk, the Institute has powerful influence. As one example, President Hockfield articulates "the power of leading by example is important to MIT and for facilitating change...[we must] develop programs, adopt technologies, and innovate approaches that model sustainable energy practices on our campus."[100]

[100] http://web.mit.edu/erc/ERC quote

Part III

Orchestrating Innovation:

the Integrative MIT Triad of Research, Education, and Extracurriculars

MIT students and faculty spend time in the lab or otherwise working on research, take or teach classes, and participate in myriad outside activities for personal or professional reasons. These domains can be distinguished as Research, Education, and Extracurriculars (REX), the so-called MIT Triad.[101] But most interesting is how deeply these three domains are interwoven, how research feeds the educational process, how hobbies fuel research interests, and so forth.

No one -- neither faculty nor staff, sponsor nor student -- can direct or dictate that research leads to results as a consequence of spending time in a lab. Similarly no one can decree that material be learned just because of time spent in a classroom. And certainly no one can impose a rich community experience on people despite their proximity. Instead each of these are domains of the Triad where people -- faculty and administrators, students and staff -- can exercise levers of influence, creating formal and informal opportunities for connection and learning, setting high standards and expectations, and offering incentives. Collectively, these surprisingly indirect methods are what maximize the odds of creative results, that is, they are means for orchestrating innovation.

3.1 Matrix Organization & Administration

MIT is a matrix organization crossing the discipline-centric departments with the project-centric research labs. [102] Over 30 departments are spread across five Schools and are disciplinary domains, the organizing basis for teaching classes and ultimately granting degrees. A few dozen large -- and upwards of one hundred smaller -- research labs and centers cut across departmental lines and are the physical and financial channels for doing research. The Deans of the Schools and the directors of the labs all report directly or indirectly to the MIT Provost, the chief academic officer of MIT.[103] The educational and student life administration of the Institute report to the MIT Chancellor.[104] The

[101] Articulated in the Task Force on Student Life & Learning Report.
[102] http://web.mit.edu/orgchart/
[103] http://web.mit.edu/provost/
[104] http://web.mit.edu/chancellor/

operational and administrative and financial responsibilities are borne by the MIT Executive Vice President.[105] These three senior Institute officers along with the head of the Alumni Association, the Secretary of the Corporation, the VP for Resource Development, and the MIT Treasurer all report to the MIT President[106] and ultimately to the MIT Corporation[107] or board of trustees.

Benefits of Matrix -- The matrix structure is tremendously flexible, partly because it separates the much slower-to-change disciplines in Departments from the fast-paced, rapidly-shifting research projects embraced by the Labs. Students (and faculty) thus have foundations and roots in a discipline while also having freedom to pursue sometimes orthogonal specific research goals.

MIT's Inputs -- Inflows to the Institute include excellent applicants, a diverse faculty, research sponsorship, and the blessings of a (usually) accumulating and appreciating endowment. Since President Walker, MIT has aggressively reached out to an ever-expanding, increasingly diverse, worldwide pool of potential candidates for admission to the Institute. Today the undergraduate and graduate programs are among the most applied for and most selective on the planet, admitting only 15% of applicants for admission.[108] And these statistics fail to capture the self-selection bias where people are daunted and do not bother applying. MIT has also reached out much more systematically to women and minorities, both as applicants for admission as well as to help create a more diverse faculty.[109]

Much of the financial sponsorship for MIT research flows from US Federal government sources, but a growing percentage are coming from international civic authorities, non-profit foundations, corporate R&D coffers, and increasingly private philanthropic contributions, including return on the MIT endowment. In the last decade especially, the Institute has dramatically increased the number of multi-year, multi-million dollar sponsor relationships, for instance the Ford-MIT Alliance, the HP Alliance, a relationship with Nokia, and the newly renewed, now $60M ten-year DuPont-MIT Alliance.[110]

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105 http://web.mit.edu/evp/
106 http://web.mit.edu/president/
107 http://web.mit.edu/corporation/
108 http://web.mit.edu/facts/admission.shtml
109 http://web.mit.edu/newsoffice/2000/diversity-0913.html
110 http://web.mit.edu/dma/www/ & http://web.mit.edu/newsoffice/2005/dupont.html

Faculty Governance -- The enduring core of the Institute are the faculty who spearhead the research, teach the courses, and ultimately are a major attractor for the students coming to the Institute. Unlike at many peer universities, the MIT faculty form a unified body and are not balkanized into undergraduate versus graduate, or one school versus another.

Faculty leaders -- including the Deans and the Chair of the Faculty -- meet together as the Academic Council, the consultative body which advises the President and has a powerful role in determining policy and direction. President Compton created the Academic Council as a mechanism to formalize and regularize the advice he was getting from diverse quadrants in MIT. Representing senior officers and the elected Chair of the Faculty, Academic Council represents "the President's cabinet [and] confer on matters of Institute policy."[111] Bob Redwine, who stepped down after nearly six years of service as Dean for Undergraduate Education in 2006, points out how the "tradition of senior academic and administrative leaders coming together regularly to compare notes, reach consensus on important issues, and advise the President of MIT, is a major strength of our system of governance. I do not know of any other university which has a more effective way for faculty to participate strongly..."[112]

For many issues, and especially for important or contentious issues, the regular meetings of the faculty are a form of limited participation in making decisions at the Institute, but, in the final analysis, decisions can and have been taken (albeit rarely) by the President acting without faculty support or consensus. While collegial and friendly under most normal conditions, in the final analysis, MIT is a private enterprise, non-profit to be sure, but run ultimately as private property with the authority running through the hierarchy up through the President who ultimately answers only to the MIT Corporation, the Board of Trustees who legally owns the Institute and governs it overall.

The faculty do have unusual power in the private enterprise, however, and through monthly faculty meetings where only they have authority to speak, do vote and take decisions on matters of research and educational policy. [113] While these faculty meetings have had sometimes lackluster attendance, under certain conditions, for instance during times of intense controversy or wartime or tremendous Institutional

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[111] http://web.mit.edu/evp/committees.html
[112] http://web.mit.edu/fnl/volume/184/redwine.html
[113] http://web.mit.edu/faculty/meetings.html

stress, these regular meetings are an important source of institutional constancy and governance.

3.2 R = Rigorous Research

Nearly one thousand faculty, ten thousand students, and several thousand researchers, post-docs, and support staff spend the majority of their professional time focused on the discovery of new knowledge, invention of new technologies, and the practical instantiation of creative ideas. In recent years, governmental, corporate, philanthropic, and other sources have sponsored roughly US$600 million of on-campus research (and an additional several hundred million at the off-campus, MIT-run Lincoln Labs)[114].

This research sponsorship flows through several hundred research initiatives, labs, centers, institutes and other institutional structures. The largest of these labs include the Plasma Fusion Center, the Computer Science and Artificial Intelligence Lab (CSAIL), the Research Lab for Electronics (RLE), the Media Laboratory (ML), the Microsystems Technology Lab (MTL), the Center for Cancer Research (CCR), the Materials Processing Center (MPC), and many others.

The measures of excellence in research are a concert of rigor in execution, creativity in approach, priority in accomplishment, elegance of results, and influence and impact everywhere relevant.

3.3 E = Transformative Education

A couple thousand undergraduate and graduate students arrive at MIT every year and ultimately graduate with a degree granted by one (sometimes two) of a few dozen departments in a specific discipline. Average tenure for undergraduates is just over four years, for masters students two years, and doctoral students over five years.

The departments are also the home base for the hiring and promotion of faculty, with on average several dozen new faculty hired every year and between one and two dozen achieving tenure status annually.

These faculty have the dual responsibility of performing research in their fields and teaching in a classroom setting. The nature of these courses varies across a wide spectrum, however, from the required core classes introducing several hundred students to the foundations of disciplines, to later stage elective offerings.

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[114] Data all from MIT Facts or MIT Institutional Research http://web.mit.edu/ir/

Generally the mode of teaching varies by discipline but lecture-style with regular problem sets dominates in the majority of courses, with reading-based and case-discussion classes are also prominent especially in the social, policy, and business offerings.

All students have a core laboratory requirements and this has been a particularly active area for new course development.

Finally, almost all students choose to participate during their schooling in at least one of over a hundred small-size elective seminar offerings. These play an especially important role in the MIT landscape.

Curricular Innovations -- Three curricular innovations at MIT especially stand out -- IAP, UROP, and Action Labs -- and each of these represent a remarkable, quintessentially MIT-style approach to learning-by-doing.

- **IAP** -- the Independent Activities Period[115] is a one-month mini-semester in January when students can take any of several hundred non-credit and credit-bearing elective offerings, work on preparatory study or special projects, or travel, or generally pursue their choice of "independent activities." This major modification to the academic calendar was initiated in 1970 as one response to the relatively rigid and lock-step nature of the required curriculum and dense schedule. The result is a period which challenges the student to take the initiative and make maximum use of the time.[116]
- **UROP**[117] – the Undergraduate Research Opportunities Program allows students to work as junior research colleagues with MIT faculty, for credit, pay, or on a purely voluntary basis. Undergraduates learn techniques, explore a field, connect with faculty advisors, and, at best, are front-line contributors to advancing a field of research.
- **Action Labs** -- are field experiences where teams of MIT students work together to solve practical, real-world problems, whether designing an incubator or hammer mill in D-Lab,[118] or exploring market potential of an emerging technology in I-Teams,[119] or working for a local company CEO in E-Lab,[120] or helping

[115] http://web.mit.edu/iap/
[116] http://web.mit.edu/mwpstr/www/node11.html
[117] http://web.mit.edu/urop/
[118] http://web.mit.edu/d-lab/
[119] http://web.mit.edu/deshpandecenter/iteams/index.html

research sponsors transfer technologies via Digital Innovation Labs,[121] or tackling the challenges of larger companies via Tiger Teams.[122]

3.4 X = Extracurricular Community

Beyond research in a lab, or taking classes towards a degree-program, students are immersed in an intensely vibrant environment laced with extracurricular opportunities. Whether through living arrangements or social clubs or professional organizations or myriad activities and events, these extracurriculars are simultaneously a seemingly distractive time-burden as well as a powerful inspiring and integrative force in student life.

Most undergraduates live either on campus or in MIT-affiliated living groups. Many graduate students do as well and those who live off-campus often do so with colleagues and classmates from the Institute. Students can opt into any of several hundred sport teams, social clubs, arts groups, ethnic societies, cultural organizations, professional-development clubs and more.

While many of these are informal activities that help fill scarce spare hours or allow students to unwind from work, several of these activities and the social commons play a special role in the MIT landscape.

3.5 The Social Commons

Many students are geographically dispersed around campus or in the surrounding neighborhood. Faculty, staff, and students are all pressed for time and usually busy on their individual projects. Too rarely do they have time to connect with friends, never mind meet people entirely out of their social, residential, and academic circles. It is to help address this challenge, this connections-bottleneck, that regular, friendly, intellectually-engaging events, all hosted in congenial social common space are enormously important. Such physical space is all too regrettably rare at MIT, but a few outliers are worth considering, the few examples of the social commons which do currently stand out.

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120 http://entrepreneurship.mit.edu/elab.php
121 http://web.mit.edu/innovation/details.shtml
122 http://lfm.mit.edu/index.php?cat=academic&fileName=courses.html#48

Grad Student Pubs

The MIT campus is home to three pubs, the Muddy Charles, Thirsty Ear, and the administration-run R&D. Each play an important role in supporting informal, social and intellectual ferment among graduate students, post-docs, faculty, staff, and visiting alums and friends.

MIT Muddy Charles Pub[123] -- The Muddy has been in operation at MIT since 1968, run by a professional manager and overseen by a volunteer Board of Governors. The Muddy welcomes faculty and graduate students, hosting events and informal activities and being a friendly venue for inventive and entrepreneurial conversations.

As documented in The Venture Cafe[124] and The Economist, "...the Muddy Charles bar, where people on the make gather on Monday nights to network."[125]

Many clubs and initiatives have been born at the Muddy, including the founding of TechLink, the cross-campus grad student connections club, the TinyTech Club for those interested in micro-thru-nanotechnologies, and the MIT Energy Club, a student-led club whose efforts both preceded and anticipated more formal Institute initiative in the energy domain.

MIT Thirsty Ear Pub[126] -- The Thirsty in the basement of the Ashdown graduate student residence hosts regular and special events including Trivia Nights, Karaoke, live bands, and the Hillarium comedy-music evening. This centrally-located Institution of the Institute is staffed by graduate student bartenders.

Function & Event Areas

For an Institution the size of MIT, there is a surprising shortage of function areas, space to run events, but the few that stand out are heavily used. Faculty and formal MIT activities most often use the Stata Center, both the major auditorium for speakers and the function space upstairs for faculty and event dining. Surprisingly, the Faculty Club at the Sloan School, while used for special events,[127] has not served as a luncheon club for the faculty in decades, since a cost-cutting move in the 1980s. Legal Seafood in Kendall

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[123] http://web.mit.edu/muddy/
[124] http://www.theventurecafe.com/
[125] http//www.economist.com/displaystory.cfm?story_id=976946%20 & http://web.mit.edu/muddy/press.htm
[126] http://web.mit.edu/thirsty-ear/
[127] http://web.mit.edu/dining/catering/mitfacultyclub/

Square has hence become the de-facto luncheon and dinner club for faculty. Both Kresge and Wong Auditorium are heavily booked for conferences and special events. Less well known but quite nice for special events are the Media Lab Lower Level, outside Bartos Theater, and the wonderful MIT Museum, the Institute's innovation archive.

MIT's Surrounding Neighborhood

The neighborhood surrounding the Institute is not only full of major firms, corporate research labs, and startup companies, but is home to dozens of pubs, restaurants, clubs, and a few major hotels. Some of the watering holes are special favorites of student groups, post-docs, faculty, and alumni alike. The nearby hotels especially serve an important role in adding to MIT's conference and event capacity. The Hyatt to the west, University Park to the north, and both the Marriott and Sonesta to the east have all supported conferences, executive education, special events, and more.

3.6 Valuing Formal and Informal Social Connections

Students and faculty interact with one another under many formal circumstances, for instance, in advisor meetings, qualification exams, classrooms, lab discussions, conferences and more. And yet many of the most important interactions are under rather less formal conditions, ranging from seminars with food and drink, to student driven discussion groups, to regular lab socials, to informal events on campus. And by no means are these explicitly "entrepreneur-oriented." Indeed, some of the most powerful connections are serendipitous side-effects as people meet each other in intellectually vibrant settings with free-flowing ideas and a congenial environment, often with food and drink and a friendly host. A few examples might serve to illustrate this.

MEMS Lunches & MNSS Seminars -- The Microsystems Technology Lab (MTL), for instance, hosted regular MEMS (Micro-Electro-Mechanical Structures) Luncheons to bring together the many users of their facility for short technical presentations and pizza.[128] This effort continues today with the Micro-Nano Seminar Series (MNSS) faculty and student gatherings run by MTL in collaboration with the Research Lab for Electronics (RLE) and local industry partners.[129] The student-run seminars are intended

[128] http://mtlweb.mit.edu/mems/mems_lunch.shtml
[129] http://www.rle.mit.edu/mnss/

as peer-to-peer learning where a more experienced student might explain in tutorial form the essential "How To" of using a new machine or process.

CSAIL Dangerous Ideas Talks -- The Computer Science Artificial Intelligence Lab (CSAIL) graduate student Greg "Gremio" Marton[130] co-created the Dangerous Ideas Seminar as a way for students and faculty to float provocative and potentially crazy ideas.[131] The goal has been for this "informal seminar [...] to spur cross-pollination of ideas in the lab and to foster creativity by challenging students, faculty, and research staff with each others' ideas."[132] Since its founding in 2001, over forty instigators have been Dangerous in front of sometimes overflow seating, all attempting to be "Informal, Evocative, and Subversive".

MIT $100K Teambuilding Dinners -- The MIT $100K Entrepreneurship Competition encourages students to enter as teams. Experience with the Competition and entrepreneurship research both show that larger, more diverse teams will, on balance, perform better in pulling together a new venture plan and ultimately in starting and building a company. People are free to team up with whoever they would like, but some are a bit shy or cautious or simply do not know people with complementary skills. For instance, many engineering students have rarely engaged with finance or marketing or sales-oriented business school students. Similarly, most business school students are at one end of the MIT campus and remain somewhat disconnected from the science and engineering folks west of Carleton Street. To partly address this gap, the Competition organizers host a series of large, general and small, focused teambuilding dinners in Walker Memorial, the Media Lab, and elsewhere on and off campus, all in an effort to connect proto-entrepreneurs.[133]

Lab & Departmental Socials -- Nearly every lab or department supports informal socials. Some are entirely student-run and unofficial, for instance the CSAIL Girl Scout Benefits, where root beer and other tasty carbonated beverages are dispensed at cost on Friday evenings. The Media Lab studcomm organizes regular teas, which rove throughout the building, as well as informal drinks at the Muddy Charles Pub. Biological Engineering faculty and students convene regularly every Thursday at the Muddy

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130 http://people.csail.mit.edu/gremio/

131 http://projects.csail.mit.edu/dangerous-ideas/dangerous/www/

132 http://projects.csail.mit.edu/dangerous-ideas/dangerous/www/faq.html

133 . http://web.media.mit.edu/~jpbonsen/MIT-50K-Pix.htm

Charles Pub, Mechanical Engineering meets regularly at the Thirsty Ear Pub, and so forth.

3.7 Tight Interweave of Research, Education, & Extracurriculars (REX) Triad

The MIT Triad of research done in labs or the field, education in the classroom or towards degree program, and extracurricular hobby activities for fun or potential profit, are all richly interwoven elements of the faculty and student experience at MIT and beyond as alums.

There are certainly institutional boundaries which delineate time in lab from activity in a class or drinks at the campus pub, but each of these elements form an MIT Triad of activity. The borders are porous, and the back-and-forth between elements of the Triad incessant, as students bring their hobbies into the lab, they wonder about the commercial implications of their research, they talk about their research agendae and challenges with their friends in social settings, and more.

All cross-combinations have precedent and are accepted (i.e. R → R, R → E, X → R, E → X, etc) and when pursued with singular MIT intensity, the results are often fantastic and surprisingly serendipitous. Several case examples may prove illustrative of the general pattern and give evidence to the tremendous diversity and importance of these tangible interconnections.

R→R: Initial Research Inspires a Larger Research Agenda

Most faculty have a research portfolio, a collection of projects and students at various stages of maturity and representing different degrees of success-likelihood. A young undergraduate might pursue a seemingly crazy idea and then escalate it if the early results are promising. Or an early exploratory effort can inspire an entire group to shift direction. Or a focused effort might generalize into a broad movement.

Sociometer → HD voicemining -- At the urging of her faculty advisor, Alex (Sandy) Pentland, Media Lab graduate student Tanzeem Choudhury, along with colleague Sumit Basu, created a special purpose wearable hardware device, the Sociometer, to capture spoken audio of volunteer human subjects in an approved human-subjects experiment. The goal was to track the social networks of the wearers and extract conversational features from their conversations. The success and promise of this initial work in speech-feature analysis and modeling inspired a more general shift of the

Pentland research group towards understanding Human Dynamics by mining interactions. What originally required dedicated hardware has been scaled up and can be run on consumer-quality mobile phones.[134]

Microphotonics Roadmap → Communications Futures Program -- Professor Kim Kimmerling and colleagues in the MIT MicroPhotonics Center saw the value their peers in the semiconductor electronics sector gained from the Sematech technology roadmapping effort. They began a microphotonics roadmapping initiative (MPH-Roadmap)[135] with participation from industry to consider the short, medium, and long-term trends and challenges in the sector. This focused effort inspired a cross-disciplinary pool of researchers at MIT interested in the communications value chain more generally to draw together and create a Communications Futures Program (CFP)[136] to look at industry and technology trends and implications. This CFP has, in turn, has been a partial inspiration for the creation of Project Mercury / LivingTheFuture, a nascent research effort to use the entire MIT campus as communications technology testbed. And so the intellectual inspiration and logical link from one research endeavor to the next continues apace.

OpenSource → Distributed Innovation -- Policy graduate student Karim Lakhani became interested in the phenomenon of online newsgroups and the remarkable degree to which people voluntarily helped other users solve problems. This early interest lead Lakhani to connect with Professor Eric von Hippel whose own work found that Lead Users, instead of manufacturers, have been responsible for much new innovation. Lakhani then generalized his research and looked more widely at open source software developers, including creating a researcher community.[137] This, in turn, lead to studying the incentives and structure of highly distributed user innovation in an increasing number of domains,[138] including sports, hobbies, games, toys, and much more.

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[134] http://seattle.intel- research.net/people/tanzeem/resume.htm & http://www.media.mit.edu/research/ResearchPubWeb.pl?ID=31
[135] http://mph-roadmap.mit.edu/
[136] http://cfp.mit.edu/
[137] http://opensource.mit.edu/
[138] http://userinnovation.mit.edu/

R→ E: Research Leads to Educational Action

As domains which are the subject of Principal Investigator driven research today become more understood and established, they soon become the basis for elective and ultimately core class offerings. Classic examples of this path include quantum physics or modern biology entering the undergraduate core, or introduction to programming becoming central to most engineering cores, or modern finance becoming an expected part of the MBA core.

More broadly, fields which begin as exploratory research efforts, and then seminal papers, and soon widespread interest, escalate to the point where faculty begin to rally around what the shared research and methodological expectations are in the domain, and what the essentials are of the emerging new discipline. Several live case examples of such deliberations have been playing out for the past 5-15 years at MIT, including the realms of Media Arts & Sciences, Biological Engineering, and Engineering Systems.

Architecture Machine Group → Media Arts & Sciences -- After running the Architecture Machine Group for many years, Nicholas Negroponte teamed with MIT President Emeritus Jerry Wiesner to raise the moneys to build a Media Laboratory and a corresponding academic Program in the Media Arts and Sciences. This emergent area would cover the influence of computing and communication technologies on human interaction, weaving together aesthetics, electronics, human factors, and cognitive science. Since the Lab and Program's founding in 1985, the underlying technologies have changed several times but the core focus on human augmentation and mediated interaction endures.[139]

Applied Biology → Biological Engineering -- Since the revolution in molecular biology beginning in the 1950s and gathering steam in the 1970-80s, engineers have had an increasing interest in the realm of the life sciences. By the 1990s and early 2000s, chemical engineers such as Linda Griffith, Doug Lauffenburger, Bob Langer increasingly began looking at biomaterials, substrates for biological organism growth, and at biochemical processes. Mechanical engineers such as Peter So, Matt Lang, and Forbes Dewey increasingly employed novel imaging and probing techniques, looking at biomechanics and micromanipulation. Chemists and biologists such as Steven Tannenbaum, Peter Sorger, and Paul Matsudaira increasingly used bioMEMS, assay, and other tools to pursue scientific investigations. And electrical and civil engineers

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[139] http://www.media.mit.edu/mas/index.html

such as Tom Knight and Drew Endy began taking modularity, logical abstraction, and interconnectable building-block ideas from their disciplines and applying them to biology. Collectively these researchers and their colleagues banded together under the rubric of Biological Engineering, an MIT Engineering School Division created in 1998, and began teaching elective, lab prep, and introductory classes. By late 2005, they were ready to begin offering an undergraduate major and received Faculty approval for their program to be officially known as Course 20.[140]

Complex Projects → Engineering Systems -- Institute faculty have studied and helped create large-scale systems since the early days of MIT, with involvement in canals and waterworks, electricity generation and distribution, railroad lines, telegraphy and telephony networks and more, all over a century ago. Indeed, each engineering discipline has its own canonical complex systems problems and methodological solutions.

Increasingly, however, complex, physical, technological, big-systems design problems have emerged which require components from several engineering disciplines as part of their solution. And not just classic engineering disciplines needed to be brought to bear, but also ideas from economics, public policy, and other social sciences and humanistic arts. Faculty pursuing these ideas were formally drawn together in the 1990s into the Engineering Systems Division, an interdisciplinary research, education, and industry outreach program, granting degrees in manufacturing, logistics, systems design, and policy domains.[141]

R→ X: Research Leads to Hobbies or Spin-off Ventures

A specific research project or tool or system may directly lead to or inspire work on home hobbies, side projects, or even be the genesis of a spin-off company, the ultimate extracurricular.

AI Touch Robots → SensAble Technologies -- While pursuing his undergraduate degree in Electrical Engineering in the early 1990s, Thomas Massie imagined building a robotic arm which would operate inverse to traditional arms: instead of reaching out, it would react to a person touching it and give that person the simulated sensation of touching an object or a surface. Massie built a toy wooden model to flesh out his

[140] http://web.mit.edu/newsoffice/2006/facmtg-dec21.html & http://web.mit.edu/be/index.htm

[141] http://esd.mit.edu/ & http://esd.mit.edu/HeadLine/esdhostsworkshop.html

concept and soon built the first working prototype Phantom haptic feedback device for his thesis working with Ken Salisbury of the MIT AI Lab. Most computer users see the screen and hear the speaker, but their primary touch feedback are mere clicks on the keyboard. The Phantom allowed users to not only see complex objects on screen, but have the sensation of touching them as well. Soon other labs at MIT and beyond wanted to "buy a Phantom" as well, and Thomas began manufacturing them in his married-students dorm room, the founding headquarters for SensAble Technologies which he formally incorporated in 1993. By 1995, Thomas had won the then MIT $10K Entrepreneurship Competition as well as the inaugural Lemelson-MIT Student Inventors Prize. He and team found office space in MIT's University Park and soon connected with Bill Aulet, an MIT Sloan Fellow alumnus who would lead the company through subsequent funding rounds, new product lines, and further growth.[142]

LCS Network Algorithms → Akamai -- In 1995, Tim Berners-Lee challenged his MIT colleagues to solve the "congestion bottleneck" problem facing the World Wide Web. Mathematician colleague Tom Leighton viewed this as an interesting algorithms challenge and, together with grad student Danny Lewin, began creating dynamic routing mechanisms which would intelligently shift desirable content to users via the most efficient pathway. By 1998, Lewin connected with long-time friend, MIT Sloan MBA student Jonathan Seelig, and entered the then MIT $50K Entrepreneurship Competition, making it to the Finalist round (but not winning). They then teamed up with IT industry veterans, formally licensed technology through the MIT TLO, raised venture financing, and by 1999, launched commercial service. The firm continues today, post-IPO and post-dotcom era, as a key player in the internet infrastructure sector.[143]

MEMS Drug Delivery → MicroChips -- Professor Bob Langer, a prolific MIT inventor and expert in drug delivery systems, imagined making drug delivery chips after viewing a documentary on the making of computer chips. Langer floated this idea by colleague Michael Cima who in turn proposed it as an exploratory project for John Santini, then visiting MIT as a summer scholar while still pursuing his undergraduate degree at the University of Michigan. Santini came back to the Institute full-time for Material Science graduate studies in 1994 and by early 1999 had a working prototype, his PhD, broad US Patent protection, and a Nature scientific publication. Santini and faculty advisors

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[142] http://www.sensable.com/
[143] http://www.akamai.com/ & http://mitworld.mit.edu/video/199/

Langer and Cima decided to team with Polaris Ventures partner Terry McGuire to create MicroCHIPS, a startup company to commercialize the technology. Since founding, the company has raised several million dollars in further venture financing and, more recently, strategic investment from leading US medical device companies.[144]

E→ E: Prototype Classes inspire New Offerings and even Course Re-design

Seminars and discussion groups sometimes inspire more substantial educational offerings or spin-off classes and occasionally escalate to become new required core classes.

New Enterprises → E-Lab, G-Lab, I-Teams... -- Since the 1950s, MIT Sloan has had an elective course offering on New Enterprises, a business planning class.[145] This course was influential on many MIT entrepreneurs including Bob Swanson, who later went on to co-found Genentech, as well as Axel Bichara and Jon Hirschtick, who created the first Windows-based CAD software company (and went on to more companies and roles in VC), and many others. In 1995, TLO Director John Preston and Professor Eric von Hippel decided to complement the business planning class with a field-lab element, and with support from the Kauffman Foundation, launched the MIT Entrepreneurship Lab (E-Lab), the first new full-semester course offering in Entrepreneurship at MIT Sloan since New Enterprises.[146] E-Lab placed teams of students with CEOs of startup companies to work on challenges directly relevant to the executive. Some of these students went on to join the ventures they engaged with during class. The E-Lab offering, in turn, was partial inspiration for Professors Simon Johnson and Richard Locke to create Global Entrepreneurship Lab (G-Lab) in 2000, a course where students advise CEOs of internationally-based companies.[147] Finally, the success of this MIT-style "business laboratory" field experience inspired students to propose and create I-Teams in 2003, now a joint-venture class between Deshpande Center and Entrepreneurship Center where student teams work with Deshpande grant-recipient to plan "go-to-market strategies" for their promising inventions.[148]

Developmental Entrepreneurship → Digital Innovations -- At the end of Spring 2001, the joint HBS-Media Lab course on Technology and Competitive Strategy polled

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[144] http://www.mchips.com/ & http://web.mit.edu/newsoffice/1999/microchip.html
[145] http://entrepreneurship.mit.edu/entre_courses.php#15390
[146] http://entrepreneurship.mit.edu/elab.php
[147] http://entrepreneurship.mit.edu/glab/
[148] http://web.mit.edu/deshpandecenter/iteams/index.html

students and discovered that three-fifths were interested in technology and entrepreneurship for international development. Coincident in time was the new Digital Nations initiative and the formation of Media Lab Asia (MLA), both efforts by the MIT Media Lab to better connect with emerging regions and bring design and technology to bear on solving pressing humanitarian problems. Hearing of this demand, MLA founding director Professor Alex (Sandy) Pentland decided to launch an exploratory seminar on Developmental Entrepreneurship in the Fall of 2001, as a joint-offering listed both in the Media Lab and Sloan School, where students propose new businesses in developing countries. This popular offering has been repeated every Fall since then and has spun out over a half-dozen startup companies. It also became a role model for a new Spring semester seminar on Digital Anthropology, now called Digital Innovations (DI). In DI, teams of students explore emerging digital technologies and speculate about their potential social and business implications. This popular offering has also been offered every Spring since 2003 and, in turn, has inspired the creation of the Digital Innovations Lab, a project-lab where student teams work with corporate sponsors of research on the technology strategy and other challenges of transferring the technology into the sponsoring firm's product lines.

2.70 → 6.270 → EECS Core Re-Architecture -- Since 1970, the MIT Mechanical Engineering Department has required all students to take Introduction to Design and Manufacturing, long known by class number 2.70, now 2.007.[149] In the course, students receive a kit of parts and are instructed to create machines which compete to accomplish a task. It is a tremendous learning experience, in some cases the first time students have used the suite of tools or materials, and it has long been a favorite class.

In 1987, Mike Parker and other students in Electrical Engineering and Computer Science, admittedly jealous of the "cool class" in Mech E, decided to create 6.270, an autonomous robot design competition to be held over IAP.[150] Run for the first two years with entirely simulated robots in a videogame-like environment, the competition added a Lego-based physical element in 1989. Instead of the machining emphasized in 2.007, the EECS competition focused on integrating sensor-data and programming the autonomous on-board PC.[151]

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[149] http://pergatory.mit.edu/2.007/ & http://web.mit.edu/smcs/inaugural/mit-2.007-history-04may2005-220k.asx
[150] http://web.mit.edu/6.270/www/about/history.html & http://web.mit.edu/6.270/www/
[151] http://web.mit.edu/6.270/www/contests/

This entirely student-run IAP course is one of the drivers encouraging the MIT EECS faculty to re-engineer the core 6.00X series of courses. While still in design-phase, it is proposed that the newly re-architected classes will include a series of escalating build-it projects which will culminate in a programmable robot and mobile PC.[152]

E→ R: Summer and Class Projects lead to Thesis or Larger Research Agenda

Summer projects and class experiences can be a form of rapid prototyping and light-weight exploration of new or uncertain areas. In many such trials lead to nothing except the memories of the experience and perhaps some lessons-learned. But in several compelling cases, for both students and faculty, the educational experience provokes and inspires a deeper, ongoing research agenda.

Arch Class & iGEM → Synthetic Biology -- AI Lab Research Scientist and symbolic computing pioneer Tom Knight taught 6.313 Contemporary Computer Design class which included a session on the future of and new possibilities for computing.[153] His speculations on the power of biological substrates led him and colleagues Professor Gerry Sussman and others to develop ideas about amorphous computing. Knight taught himself modern molecular and cellular biology in order to better understand what he and colleagues today refer to as "wetware".

By 2003 Knight and colleagues Drew Endy and Randy Rettberg organized themselves enough to run the first MIT IAP synthetic biology design challenge[154] where students used relatively primitive biological design tools to create simple biological circuits. In that first year, largely oscillators, a type of circuit familiar to anyone from electrical engineering. Run again at MIT in the January IAP 2004, the competition became a five school Jamboree in the summer 2004 and the fourteen school International Genetically Engineered Machine Competition in 2005.

The student participants ranged widely in age from graduate student through freshmen, and in background, from biologist through mathematician and computer scientist. And yet as Malcom Campbell and other witnesses attest "Teams of undergraduates spent 10 weeks of their summers blending biology with computer science, engineering, and chemistry. As is often true of young students, many were oblivious of the significance of their efforts before the Jamboree. Only after sharing their stories did they begin to

[152] Rod Brooks informal discussion
[153] http://web.archive.org/web/20040307054138/www.ai.mit.edu/courses/6.313/admin/topics.html
[154] http://parts2.mit.edu/wiki/index.php/Iap_2003

appreciate the magnitude of their summer's efforts. Each group of students had been given a one-phrase directive (design and build a genetically encoded finite state machine), and over the summer, they designed, modeled, built, and tested their constructions."[155]

Informal and exploratory research by neophytes in a novel field can be very powerful because these student do not know what's "impossible" and thus go do it. In the synthetic biology area this has lead to a blossoming of interest in the field, student activity, online repositories of information,[156] shared development websites,[157] and more.

Developmental Entrepreneurship (DE) Seminar → Program in DE -- Since 2001, the joint Media Lab and Sloan exploratory studio on Developmental Entrepreneurship has encouraged students to team up and pursue business solutions to economic and social problems in developing countries. This course has subsequently incubated or encouraged the founding of a handful of companies, including WAY Systems, Dimagi, United Villages, blueEnergy, Howtoons, gyanpad, CellBazaar, and more. This exploratory class led several students to their Masters thesis, for instance, United Villages and WAY Systems, and has more generally inspired a new Program in Developmental Entrepreneurship focused on designing and implementing commercially sustainable products and services for even the poorest communities worldwide.[158]

How To Make (Almost) Anything → FabLab -- Professor Neil Gershenfeld and colleagues built up the basement machine shop in the Media Lab as support infrastructure for their research. To help attract students and share how-to lessons, Gershenfeld and colleagues have long run a highly sought-after class entitled How To Make (Almost) Anything. Every student learns how to use every tool and make just about anything they can imagine. The machine shop has further been used by students on an extracurricular basis to build all kinds of projects, both fun and serious. In some cases, the availability of the tool inspiring and provokes building things.[159]

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[155] http://www.cellbioed.org/pdf/04-11- 0047.pdf
[156] http://parts.mit.edu/
[157] http://openwetware.org/wiki/Main_Page
[158] http://web.media.mit.edu/~jpbonsen/DevEntreFall2001.htm & http://ocw.mit.edu/OcwWeb/Media-Arts-and-Sciences/MAS-666Fall2003/CourseHome/index.htm & http://web.mit.edu/de/
[159] http://web.mit.edu/iap/www/iap02/searchiap/iap-4032.html

Partially as a result of running the class and observing students, Gershenfeld was inspired to make research on technologies for personal fabrication a substantial element of the Center for Bits and Atoms (CBA), a five-year NSF funded program.[160]

E→ X: Class Projects and Coursework lead to Club Projects and Spin-offs

Required or elective classes often require or encourage projects where students have to build a working prototype, a demonstration of an idea, a crude first-cut at a future product category. In other cases, persistent problems emerge in an educational context which are worthy of further attention after class. Either way, the projects are provocative and hard and interesting enough that students and faculty keep developing things further.

2.75 Medical Innovations → Robopsy Telesurgery -- MIT Mechanical Engineering Professor Alex Slocum teaches a design and precision engineering class where Massachusetts General Hospital (MGH) clinicians present their problems to the MIT engineering students. Students team up, pick the most compelling challenge, and build a working prototype

In Fall 2004, teammates Conor Walsh and Nevan Hanumura from MIT and Steven Barrett from Cambridge University picked Dr Amar Gupta's wish for a remote-control lung biopsy system, a system which avoids the inaccuracies and lung injuries too common in the current procedure. Today doctors insert a needle partly into the lung, run a CT x-ray scan of the patient, remove the patient from the scanner, re-orient the needle, and repeat until the doctor is confident a biopsy sample can be withdrawn. This is a laborious, several hour, often painful and inaccurate procedure repeated several hundred thousand times yearly.

Walsh, et al, created a light-weight, disposable tele-operated robotic needle-insertion device. The doctor straps the Robopsy to the patient chest and places the patient in the CT scanner. Then, from the shielded control room, the doctor can control the insertion path and trajectory of the needle into the patient, all while seeing in real-time the x-ray scan of what's happening inside.

Their initial prototype effort was compelling enough that the team applied for and was granted additional funding, from several sources, for further invention development.

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[160] http://cba.mit.edu/about/index.html & http://fab.cba.mit.edu/about/

They continue to work on taking this class idea and turning it into a commercial venture.[161]

6.111 Digital Design Projects → MIMIO Electronic Transcriber -- Yonald Chery served for several years as head Teaching Assistant (TA) for 6.111 Digital Design Lab, a core MIT Electrical Engineering course for all EE students in the biggest department on campus. This projects class requires students to build an escalating series of electronic circuits culminating in a unique, student-driven original design and working system.

(Several of these student projects have been compelling and innovative enough to form the basis for new companies, for instance, Pehr Anderson's ethernet telephony venture NBX, a company later bought by 3Com for $70M.)

As TA, Yonald repeatedly used whiteboards to give design reviews and tips for student project teams. He noticed that too often he had to repeat the same tips or that the tips were incorrectly noted down.

Soon thereafter, while thinking about his business ideas worth entering in the MIT $50K Entrepreneurship Competition, Yonald recalled his frustrations with student note taking and the ephemeral nature of whiteboard scribblings. He reframed his problem as an invention opportunity and proposed an "Automatic Whiteboard Mimeographic System". This first forae into business proposals failed since he concentrated entirely on describing the technology and too little on anything else -- market size, team composition, financials, and so forth.

He is quite persistent, however, as many MIT students and proto-entrepreneurs are, and entered the Competition again, this time winning a $10K prize and subsequently founding MIMIO company to commercialize interactive whiteboard recorders thus turning his course teaching duties into a commercial MIT-spinout venture.[162]

MIT-HBS Technology & Competitive Strategy → LowCostEyeglasses -- MIT Media Lab doctoral student Saul Griffith in Professor Joe Jacobson's joint Harvard-MIT course on Technology & Competitive Strategy developed prototype Low Cost Eyeglasses (LCE) in Spring 2001. Over one billion people worldwide need corrective eyewear but either lack access or cannot afford those glasses which are on sale. There are many barriers to lowering the cost of glasses -- especially social, political, and legal -- but the technical

[161] http://forum.wgbh.org/wgbh/forum.php?lecture_id=1987
[162] http://www.mimio.com/

ones were most immediately tractable. Most lenses today are molded in a factory and then sent to retailers who have to maintain a large inventory, with all the associated capital costs. Griffith instead proposed molding glasses in the field out of much less expensive bulk optical acrylic, and he built a working lab-bench prototype to prove it possible. This prototype, plus associated business analysis, were subsequently the basis for the winning entry in the HBS Business Plan Competition in March 2001[163] and lead to LCE spin-off company.[164]

Windup Browser → $100 Laptops → One Laptop Per Child -- The Spring 1999 MIT Media Lab seminar on the Wind-Up Browser taught by Professors Joe Jacobson and Ted Selker with Teaching Assistants Saul Griffith, Rob Poor, and Rich Fletcher prefigured everything that would later be born as the MIT-spin-off OLPC One Laptop Per Child $100 Laptop.

The Wind-Up Browser class was "geared towards designing and building an information appliance for developing nations. The sole constraints were that (1) It must change the world, and (2) It must have a manufacturing cost $10."[165] This core ethos and Professor Jacobson's display technology[166] and Professor Selker's laptop engineering sensibility[167] and Saul Griffith's windup generator ideas are all elements of the new laptop initiative.[168]

2.70 Intro to Design → FIRST High School Robot Challenge -- Long-time instructor of MIT's 2.70 Introduction to Design, Mechanical Engineering Professor Woodie Flowers collaborated with inventor Dean Kamen to launch the FIRST Robotics Competition for High School students, thus taking a core required class for 150 MIT undergraduate students and crafting a similar experience for an ever-growing number of younger students -- nearly 30,000 in 2006, hailing from 33 regional areas and a half-dozen other countries.[169]

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[163] http://www.news.harvard.edu/gazette/2001/05.10/12-hbscontest.html
[164] http://www.lowcosteyeglasses.net/
[165] http://www.media.mit.edu/windup/
[166] http://www.eink.com/
[167] http://www.research.ibm.com/journal/sj/393/part3/selkeaut.html#selker
[168] http://laptop.org/
[169] http://www.usfirst.org/robotics/index.htm & http://www.usfirst.org/about/bio_flowers.htm

X→ X: Extracurriculars Inspire other Extracurriculars

Students often learn from their peers and copy them, for instance, creating a club to rally around a special interest area. Or people see one kind of event and that inspires them to take the best elements and apply it to their own situation and their own activities.

MIT $100K Entrepreneurship Competition → GNVC, BIT, PESO Business Plan Contests -- The student-run MIT $100K Entrepreneurship Competition has inspired several other schools, institutions, regions, and countrywide civic entities to found and run their own Competitions. In several cases, MIT student organizers or participants in the local $100K (then $50K) built on their personal experience and created spin-off competitions directly modeled on the MIT method:

- Victor Mallet and several fellow Ghanaian undergraduate students at MIT went back home to create the Ghana New Ventures Competition (GNVC).[170]
- Post-doc Dmitry Repin returned to Russia to start and run the Business Innovation Technology challenge (BIT).[171]
- And Political Science graduate student Neil Ruiz along with fellow Filipino MIT students and colleagues back home created the Philippines Entrepreneurial Startup Open (PESO)[172]

Muddy Charles Pub Socials → MIT Museum GradNights -- The MIT Muddy Charles Pub (the Muddy) serves the graduate student, faculty, staff, and alumni community. The Muddy has also increasingly been used as a venue for informal gatherings of interest groups, for example, entrepreneurial networking nights. The success of these smaller-scale gatherings inspired the organization of larger-scale GradNights at the MIT Museum,[173] where the Muddy bartenders would serve, food would be catered in, a jazz band would play on the side, and informal conversations would playout throughout the evening. These GradNights were, in turn, run in collaboration with other clubs or initiatives and given specific themes, including Sailing Technology, International Development Innovations, SmartCities, Robotics, and Energy Technologies. The most recent several GradNights attracted some 500 attendees each.

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[170] http://www.gnvc.org/
[171] http://www.bit2006.ru/
[172] http://web.mit.edu/peso/
[173] http://web.mit.edu/museum/

Innovation Club → SmartCities, Robotics Initiative -- The MIT Innovation Club (I-Club) organizes dozens of activities yearly supporting inventors and people interested in the business implications of new technologies. Furthermore, the I-Club has incubated the formation of several more focused or thematic clubs, including the SmartCities Initiative and the Robotics Initiative. In the case of SmartCities, the I-Club first hosted an IdeaExchange luncheon gathering featuring speakers from MIT's New Century Cities project. This sparked conversations about urban innovations more generally -- IT in the city, GIS systems, road-pricing, new design techniques, and much more. During the following summer, a core team including Susanne Seitinger and Gena Peditto began planning a new club, the SmartCities Initiative[174] to pull together the very fragmented landscape of interested folks interested in these themes. The MIT Innovation Club co-hosted the kickoff event at the MIT Museum.[175] Similarly Robotics are a pervasive theme of interest at MIT, but the players are distributed throughout the Institute. Furthermore, there is tremendous latent interest in robotics among students, alumni, faculty and their children. So with I-Club support, several interested students ran a kickoff event for the Robotics Initiative, a RoboNight, again at the MIT Museum.[176]

X→ R: Hobbies and Club Activities lead to Research Endeavors

Personal hobbies, club activities, homebrew build-it projects, and the like, can inspire and escalate and almost become obsessions. Such projects which "have" to be pursued on a more full-time basis can readily become the genesis of a more formal research agenda.

Hobbyist Wearable Electronics → Wearable PC Movement -- Thad Starner while doing his research in computer vision and modeling in the MIT Media Lab wanted to wear his computer so he could take notes and, more importantly, remember what he wrote. Steve Mann built custom wearable celluloid-film camera and flash systems so he could perfect his particular type of artistic immersive photography.

Both Starner and Mann built some of the earliest digital wearable computers as hobbyists. They and other colleagues at MIT, however, seeded and gave birth to the wearable computing movement which ultimately became the basis for research agendae in several groups in the MIT Media Lab and the genesis for a new field.

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[174] http://web.mit.edu/smartcities/
[175] http://web.mit.edu/smartcities/events.html
[176] http://mit.edu/museum/about/news/robonight.html

Both their efforts were made possible and encouraged by the friendliness of their MIT professors to their seemingly crazy hobbies. Their advisors -- Professors Alex (Sandy) Pentland, Rosalind Picard, Pattie Maes and others -- actively supported their students in ways going well beyond money and advice on narrow research topics. This friendly faculty "incubation ethos" allowed this compelling research theme to emerge and bubble up to prominence.

Thad Starner, for instance, invested an enormous fraction of his time on building the community of interest and a common platform for wearable computing, the Lizzy. By being the friendly source of info, encouraging people to try wearables, answering newbie questions, welcoming people to open discussion meetings, seeding research ideas, and more, Thad inspired and provoked dozens of colleagues at and beyond MIT to incorporate wearable computers into their research agenda, co-founded or inspired the creation of several companies, and with other colleagues created ISWC, the premier regular wearables conference.

Starner has gone on to faculty role at GeorgiaTech and Mann at UBC, both continuing to pursue research towards a wearables-everywhere future world.

Home-built Three-Dimensional Printer → 3DP Patents → Z-Corp -- Tim Anderson and Jim Bredt worked in Mechanical Engineering Professor Ely Sach's Three-Dimensional Printing (3DP) group as technician and doctoral student. At the time, 3D printers used very expensive custom nozzles, challenging adhesives and materials, and were generally complex to work with. Tim and Jim working on their own in the MIT Electronics Research Society (MITERS) space in the old MIT Building 20 decided to build a "hack" 3D printer.

Instead of a complex nozzle they borrowed an ink-jet head from an off-the-shelf printer. Instead of complex adhesives or binders, they used water. And instead of special purpose materials, they used sugar, which, when wetted, sticks to itself. By spraying water on sugar in a systematic pattern, layer upon layer, they could print a sugar cube with a specific shape. In other words, they could print a piece of candy.

In retrospect this seems obvious. But at the time, they were almost embarrassed by their project. It was so low-end compared to the sophisticated 3DP's in the lab and it was also "unauthorized." They never sought permission to do this related work on their own, they just did it. When they worked up the courage to show Professor Sachs, he was delighted and this lead to further, more formal engineering work. When later the entrepreneurial couple Marina Hatsopoulos and Walter Bornhorst visited the MIT Technology Licensing Office (TLO), that office introduced them to Tim and Jim. Together they all founded Z Corporation, which in its first decade of operation grew to employ over 100 people, serving over 1,000 customers, and being the acknowledge leader in the billion-dollar 3D printing market.[177]

Design-that-Matters → ThinkCycle → Instructables -- Media Lab graduate student Nitin Sawhney, and colleagues, combined their coding skills and interest in global development to create an online connection database linking those with challenges with those whose engineering and technical skills could help solve those problems. They created an extracurricular seminar offering called Design-that-Matters to rally MIT students interested in these topics and built the ThinkCycle system to support the seminar and other projects online. What began as an extracurricular effort escalated to become Sawhney's doctoral thesis. Ultimately the ideas behind ThinkCycle inspired further websites, including the Instructables effort out of Media Lab spin-off company Squid Labs.[178]

X→ E: Informal Seminar or Club Project Leads to Class Offerings

When students or faculty see a gap in the lineup of formal MIT activities or classes, and they feel it is a serious lack or open opportunity, then they're likely to fill the gap by just doing it, by running an informal seminar or organizing an informal side project. Such efforts can escalate into more formal, credit-bearing class offerings.

Design-that-Matters → D-Lab -- The same MIT Media Lab student team which founded and created ThinkCycle ran an informal design seminar starting in Spring of 2001 for any student interested in applying themselves to solving pressing global development challenges.[179]

Design-that-Matters (DtM) in the Spring semester of 2001 was partial inspiration for the credit-bearing 15.971 / MAS.967 Developmental Entrepreneurship[180] which is about business models for deploying such designs everywhere.

[177] http://www.zcorp.com/
[178] http://www.thinkcycle.org/ & http://www.instructables.com/ & http://www.squid-labs.com/
[179] http://www.designthatmatters.org/programs_courses.html
[180] http://courses.media.mit.edu/2001fall/mas967/

Furthermore, the non-credit DtM student effort became formalized as part of the D-Lab series of credit-bearing offerings, inspiring the founding of a DtM student club, now called Design-for-Change[181] and spun out a 5.01(c)3 non-profit in June 2003.[182]

MIT $100K E-Competition → IAP Nuts & Bolts of Business Plans Seminar -- The MIT $100K Entrepreneurship Competition began in 1990 (with a mere $10K), a joint-venture between Engineering and Sloan entrepreneurship clubs as a publicity vehicle and way to inspire students to learn about planning and starting companies. By the second year, the student organizers talked MIT Senior Lecturer Joe Hadzima[183] into teaching an informal IAP session on the Nuts & Bolts of Business Plans. As Hadzima tells it, "one student, Phil Greenspun, placed the offering in the IAP guide and then told Joe "I dare you not to show up. You have to teach it." The Nuts and Bolts was quite appealing and drew several hundred students from across MIT to main lecture halls 6-120 and then 10-150 for an intensive overview of business and planning.

By 1994-5, the MIT Center for Entrepreneurship had been re-invented as the MIT Venture Initiative focused on new course offerings, and thus the time was ripe for adding to the portfolio. By adding a writing assignment and additional course hours to the schedule, and getting Joe Hadzima to agree to be faculty in charge of the course, the then MIT $10K Lead Organizer orchestrated one of the first 3-unit credit-bearing entrepreneurship offering in the MIT Sloan folio out of what was before purely extracurricular. The class is still offered and continues to draw the largest numbers of students any MIT Sloan entrepreneurship offering.[184]

MIT Energy Club → IAP Offerings -- MIT Energy Club founder Dave Danielson wanted to "Bring together the energy technology, policy, and business communities @ MIT"[185] and created the club as a vehicle for accomplishing this goal. While Energy research pervades MIT and President Hockfield had charged the Energy Research Council (ERC) with charting future directions for Institute energy efforts, there was a surprising absence of information exchange and informal community among those interested in energy-related topics.

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181 http://web.mit.edu/dfc/www/
182 http://www.designthatmatters.org/
183 http://entrepreneurship.mit.edu/15975/staff.php
184 http://entrepreneurship.mit.edu/15975/index.php
185 http://web.mit.edu/mit_energy/

The club has since escalated to running one or two events every week, organizing a major MIT Energy Conference in May 2006[186] and collaborating with the MIT Enterprise Forum Energy Special Interest Group in promoting and organizing the Ignite Clean Energy Competition (ICE).[187]

Furthermore, the MIT Energy Club members organized several January Independent Activity Period (IAP) non-credit offerings and were instrumental in creating one credit-bearing seminar, the first ever MIT offering on Energy Mega Projects.[188]

3.8 Orchestrating Serendipity

Often underappreciated is the power and importance of good advice, well given. The ideal faculty advisors, for instance, not only care about their students as work production units who crank out publishable results, but are deeply interested in helping launch them on a productive career, whether in academia, industry, or elsewhere. Great advisors have developed good taste and refined judgment about what is worth doing, what areas are of high potential future impact, are intellectually interesting, and have growing promise. Even if the advisee does not immediately see the importance of a domain, thoughtful advisors will nevertheless be firmly encouraging, not dictatorial, but also not letting a promising direction go underappreciated. The advisors might insist on a literature review of a particular area, anticipating that it will trigger more intense student interest. Or similarly, the advisors might urge an exploratory project, just to see if a domain has promise. Good advisors might also support and channel the emergent interests of the advisee, sometimes spending substantial moneys for equipment or conferences or field-experience, all in order to fuel a powerful intellectual passion.

The resulting informal and informal connections, discoveries, and inventions -- and the sometimes unexpected consequences -- are, in effect, a means of orchestrating serendipity. Some of the most interesting results of effort are not the straight predicted or hoped for ones. While scientific and technical progress is sometimes a straightforward matter of pushing towards and achieving goals, more usually where one ends up is not where one originally set out for. The best advisors and labs, (and ultimately the Institute as a whole) have a dynamic flexibility and willingness to embrace new ideas, novel notions, and twists in the path to discovery or invention.

[186] http://mitenergyconference.com/
[187] http://www.mitforumcambridge.org/EnergySIG/IgniteCleanEnergy.html
[188] http://web.mit.edu/mit_energy/IAP_Courses/index.html

Part IV
MIT Entrepreneurial Ecosystem:
Formal and Informal Web of Inspiration, Connections, and Tangible Venture Support

The entire MIT campus exists and operates to support ideation and exploration in general. But going from academic inquiry to real-world impact often requires several tangible mechanisms and practical means to help transfer technologies, educate engineers about entrepreneurship, inspire activism, and more.

This movement of ideas "from lab to living room" is enabled and facilitated at MIT by the workings of a rich entrepreneurial ecosystem weaving together alumni and faculty role models and advisors, formal offices and program, informal extracurricular clubs and competitions, infrastructure supporting creative invention, the technology venture zone surrounding campus, and creative innovation networks in the greater Boston-metro area (and increasingly around the world and online).

4.1 Faculty & Peer Advice: The Power of Mentorship & Engagement

The very action of bouncing back and forth between academia and industry is tremendously provocative for faculty, is inherently transdisciplinary, and often provokes entrepreneurial ideas. From an academic perspective, dealing with tangible challenges of industry keeps faculty fresh and even has a rejuvenating quality. Industry is also a potential source of synergistic relationships -- research sponsorship, consulting connections, summer and post-graduation employment for students, a source of instrumentation or materials and more.

While startup connections are the most visible and most substantial, they are also much less frequent than consulting or advisory board links. And it is as advisors and mentors that many faculty exert greatest influence on students and their peers. Certainly some are formal co-founders of companies, but vastly more are simply interested in the professional development and growth of students -- and fellow peer faculty -- who care about.[189]

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[189] MIT Materials Science Professor Gene Fitzgerald remarks at a Graduate Student Council Talk, August 26th, 2004

4.2 Role Models: MIT's Hall of Heroes

Carved in stone on the porticos surrounding the great grassy Killian Court at the heart of the MIT campus are dozens of names. These men and women were not great sportsmen, nor politicians or generals or other figures of classic cultural import. Instead they are the scientists and engineers who in centuries and millennia past were the discoverers and inventors of new knowledge and new methods. These are MIT's Heroes.[190]

In the modern era, largely since the time of those names were carved, a new set of MIT heroes has emerged. Many are great scientists or engineers who have pioneered new fields. Many more are those who have gone out into industry and founded companies, building new products, supplying services, and occasionally giving birth to entirely new industries. Their stories can never be told too frequently as examples inspiring a new generation of student inventors and entrepreneurs.

Bell's Telephone -- Alexander Graham Bell was a professor of audiology at Boston University with ideas for building tools to aid people, especially the deaf, in vocal communication. MIT Physics Professors Pickering and Cross opened their lab to Bell and helped give birth to the telephone, perhaps the first university-research based media innovation. Of course, much further refinement and technical improvements and infrastructure deployment was required before people could call each other over great distances and live the geographically separate but instantaneously connected modern lifestyle.

One dramatic refinement occurred on the edge of the current MIT campus. In a Cambridge building today owned by MIT and housing Shire pharmaceuticals, Thomas Watson placed the first long-distance phone call over telegraph lines along Main Street leading over the Longfellow Bridge to Bell sitting at what today is the edge of Government Center in Boston.

Hollerith's Computing & Tabulating Machines -- Francis Amasa Walker had run the US Census for two decades prior to becoming MIT President in 1881 and was intimately familiar with the great challenge facing his successors: the time involved in hand counting forms and analyzing results would exceed the decade between each Census.

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[190] http://libraries.mit.edu/archives/exhibits/names/index.html

Walker attracted to MIT a young faculty member of Mechanical Engineering, Herman Hollerith who had worked at the Census Bureau and had some ideas about potential solutions. Indeed, he would go on to invent a series of computing and tabulating machines which indeed addressed the problem. The company Hollerith formed to commercialize and produce these machines we today know by its modern name, IBM.[191]

Nickerson's Blades -- In the late 1890s, a Boston-based bottle cap salesman hit upon a compelling idea: what if he could sell a disposable safety razor which would allow men to shave (cheaply) with much less fear of suffering slit-throat from the straight barbers blades of the day. Good idea, but he was unable to actually smith the blade until he teamed up with William Emery Nickerson, MIT alumnus and metallurgist. In 1901 they formed the American Safety Razor company together, a firm soon known by the name of the salesman, King Gillette, and now part of the Procter & Gamble empire.[192]

Green's Instruments -- After Cecil Green graduated MIT in 1923, he and his wife Ida ended up in Texas working at Geophysical Service Inc (GSI), a seismic oil exploration company. By 1941, he and partners had bought the firm and began electronics development during WWII. Pretty soon more people were interested in their instrumentation than geophysical services so they decided to create a company to pursue that sector. But what to call it? They were in Texas and built Instruments and thus began TI, a firm which today employs over 35,000 people worldwide and is market leader in DSP, display, and other electronics.[193]

4.3 Catalytic Connectors

Popular and academic business literature documents the importance of "Management by Walking Around", a style of paying attention to the organization, exerting influence on its people, and crafting an open culture perhaps best popularly exemplified by MIT alumnus Bill Hewlett and his partner Dave Packard, the co-founders of HP.[194]

Such a style has deep roots at the Institute as well. President Walker, for instance, was famous for his open door policy in the 1880s. President Killian discovered the importance of informal visits and prowling the corridors while serving as editor of

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[191] http://www.maxmon.com/1890ad.htm
[192] http://www.gillette.com/ & http://web.mit.edu/Invent/iow/gillette.html & http://www.uh.edu/engines/epi738.htm
[193] http://www.ti.com/corp/docs/company/history/green.shtml & http://www.ti.com/
[194] http://www.hp.com/hpinfo/abouthp/histnfacts/timeline/hist_40s.html

Technology Review in the 1920s. Killian kept up this style of information-gathering through unofficial channels, and thus listening to a range of opinions, throughout his later service as President and Chairman. More recently, Provost Mark Wrighton was known for showing up at the door of deans, faculty, and administrators to have a preliminary chit-chat rather than call or email or use more formal memoranda or committee meetings. This style is not only followed by top leaders of the Institute but is a very important mode of distributed leadership, with administrators, faculty, and even students also serving in a connective capacity.

Certainly not all administrators or faculty or Presidents, for that matter, were comfortable with or able to use quick hallway conversations or informal reconnoitering, but there are dozens of crucially important connectors roaming the halls of MIT on a regular basis. These are students and administrators, faculty and alumni, who all have an interest in Institute happenings beyond their narrow individual brief. They are curious and friendly and have fairly wide knowledge about who is doing what or how to get things done or about essential elements of Institute lore.

These people are linkers, information routers (to use modern network parlance), and they catalyze creative connections by lowering psychological and social barriers: by introducing folks to one another, making key suggestions to resolve challenges or bridge gaps, being a sounding board for new ideas, or helping people think past sticky points. Such catalytic connectors are valuable elements of any organization or to many individuals pursuing their day-to-day work, but they are especially important when MIT people seek to do things beyond their normal mode, for instance, when a scientist or engineer becomes interested in the possibility of founding an entrepreneurial startup to commercialize their ideas. These proto-entrepreneurs seek advice and connections and introductions and information which are rather different from what they normally need and so it is at this juncture that the catalyst can play a crucial role.

4.4 Entrepreneurial Support Systems at the Institute

As highlighted earlier, MIT has a long history of supporting industry links and entrepreneurial endeavors. Today, new venture development is bolstered and encouraged at MIT by nearly two dozen different offices, programs, centers, alumni activities, and student-run activities. There is no one entity through which all-things entrepreneurial flows, and no one director or administrator or individual who decides what happens, or which entrepreneurs get support or not. It is a highly distributed, and yet mutually-reinforcing system.

This support system is itself the product of the same entrepreneurial ethos that pervades MIT. Many people during their time at the Institute saw a need and acted to fill it. Furthermore, they did not particularly want to be beholden to someone else (a "boss") and so they simply went and started a their initiative. From an outsider's perspective this may seem fragmented and messy, but in practice, over time it is an approach that is robust and enduring because there is no one failure mode and, indeed, multiple nodes of support.

While many of these groups are run autonomously, there are nevertheless tremendous cross-collaborations, especially towards specific projects or events or joint-ventures in education or conferences.

Entrepreneur Services & Directed Support

MIT Enterprise Forum -- The MIT Enterprise Forum network was born out of an Alumni Association series of events featuring MIT Sloan Professor Ed Roberts and other alumni entrepreneurs in the early 1970s. Demand was so high in different cities throughout the US that the Association supported creating a volunteer-run MIT Enterprise Forum to provide advice, support, and educational services to technology-based companies of all sizes. The Enterprise Forum Global network today includes a Cambridge Chapter which hosts monthly case and start-up presentations, annual large venture workshops, short program offerings, and Sectoral Interest Groups (SIG) focused on specific technology business sectors, for example Energy, RFID, Advanced Computing, and Nanotech. The Energy SIG co-sponsors the annual Ignite Clean Energy (ICE) business plan competition.[195]

MIT Chairman's Salons -- Hosted since the late 1990s by MIT Corporation Chairmen Alex d'Arbeloff and Dana Mead, and co-organized by an alumni team lead by Robert Wickham with the essential support and encouragement of the Resource Development team of fundraisers and the MIT Alumni Association, these twice annual Salons have brought together hundreds of MIT alumni entrepreneurs, faculty, and key Institute

[195] http://enterpriseforum.mit.edu/
http://www.mitforumcambridge.org/

leaders in an informal setting and doing so on an Institute-wide basis without special emphasis on a particular School, or program, or constituency.[196]

MIT Venture Mentoring Service (VMS) -- The Venture Mentoring Service (VMS) was created by alumni and faculty under the auspices of the then MIT Provost Bob Brown in 2000 in order to match up-and-coming MIT-related inventors and proto-entrepreneurs with more experienced mentors.[197] The seasoned entrepreneurs reasoned that a bit of advice and active guidance would boost the odds of success for a nascent venture and that both the young entrepreneurs and the Institute would profit. Today the nearly one hundred mentors work with a similar number of company founders at various stages of venture development. These mentors also connect student teams with VMS mentee companies in the VentureShips program run with the student-run Science Engineering Business Club (SEBC).[198]

Twice per year, the VMS hosts The Entrepreneurial Edge, an informal reception in the Faculty Club for nearly two hundred mentors, entrepreneurs, and members of the MIT venture community.[199]

Deshpande Center for Technological Innovation[200] -- MIT trustee Desh Deshpande and his wife Jaishree pledged US$20M to MIT's Engineering School in 2001 in order to seed finance pre-commercial research projects which were judged to have commercial promise.

The D-Center has granted roughly half-million dollars to between five to ten faculty principal investigators every Spring and Fall, a cumulative total of 51 by Spring 2006. Nine of these grantees have spun out as independent startups and have raised a collective total of over US$40M in venture capital financing.

The D-Center runs an annual IdeaStream innovation conference connecting grant recipients and other MIT technologists with the VC community. Furthermore, the D-Center organizes regular faculty-to-faculty lunches around the challenges of commercialization, hosts Ignition Forae on emerging technology themes, and co-

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[196] http://web.media.mit.edu/~jpbonsen/ChairmanSalon.htm
[197] http://web.mit.edu/vms/about.html
[198] http://www.mit-sebc.net/vteam/
[199] http://web.mit.edu/vms/
http://web.media.mit.edu/~jpbonsen/VMS-Spring2003-Soiree.htm
[200] http://web.mit.edu/deshpandecenter/

organizes the I-Teams project lab class in a joint-venture with the MIT Entrepreneurship Center.[201]

All grant recipients are further connected with Catalysts, members of the greater Boston business community who volunteer their time to help grant recipients maximize the real-world impact of their innovations.[202][203]

MIT Technology Licensing Office (TLO) -- Run for many decades as the MIT Patent Office, the Technology Licensing Office (TLO) was reorganized in 1984 with a focus on technology transfer to the world at large and today "manages the patenting, licensing, trademarking and copyrighting of intellectual property developed at MIT, Lincoln Laboratory and the Whitehead Institute and serves as an educational resource on intellectual property and licensing matters for the MIT community."[204]

This office is the Institute's formal channel for technology transfer and has reporting responsibilities directly through the MIT VP of Research. It primarily serves faculty, but is generally quite friendly to inventive students, and plays an important role in teaching students about patenting and licensing through seminars and class lectures.

The TLO often counsels MIT faculty inventors that the greater Boston area is a "virtual incubator" full of mentors, advisors, angels, and others eager to help facilitate new venture creation.[205]

Educational Programs

MIT Entrepreneurship Center (E-Center) -- Begun as the Center for Entrepreneurship in 1990 by Professor Ed Roberts, and developed further as the MIT Venture Initiative under Professor Eric von Hippel, the MIT Entrepreneurship Center has continued to operate its MIT-wide activities under Senior Lecturer Ken Morse since 1996. The E-Center seeks to increase understanding of new enterprise development, teach skills fostering entrepreneurship, and nurture new business ideas by supporting research, teaching, and collaborating with MIT's many entrepreneurship activities. Housed in the MIT Sloan School of Management, the E-Center serves students across the Institute

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[201] http://web.mit.edu/deshpandecenter/iteams/index.html
[202] http://web.mit.edu/deshpandecenter/catalyst.html
[203] http://web.mit.edu/deshpandecenter/
http://web.mit.edu/deshpandecenter/release_010202.html
http://web.media.mit.edu/~jpbonsen/DeshLink-PortableEnergy.htm
[204] http://web.mit.edu/tlo/www/
[205] http://web.mit.edu/tlo/www/MITsystemtechtrans.pdf

through nearly two dozen classes, special executive education programs, social and entrepreneurial networking events, and by supporting several of the core entrepreneurial student groups.[206]

In recent years, the MIT Entrepreneurship Center has substantially grown its suite of academic course offerings in entrepreneurship, including most recently I-Teams, a joint-venture with the MIT Engineering School-based Deshpande Center wherein student teams assess the commercial prospects of Deshpande-sponsored faculty research.

Public Service Center (PSC) -- MIT students, faculty, and alumni have a history of informal public outreach and service that is as old as the Institute. These efforts were formalized and organized in 1988 with the founding of the Public Service Center (PSC) under the patronage of Priscilla Gray, wife of then-President Paul Gray.[207] Since then, the PSC has been a source of financial and moral support for thousands of students and, through its programs and activities, has spearheaded practical hand-on service learning with real-world community benefits. The PSC co-created and runs the IDEAS Competition as well as the International Development Initiatives and dozens of other specialized programs. Students with PSC support have gone on to found social ventures, including Volunteer Community Connections, now United Way's online operation.[208]

Edgerton Center -- The Edgerton Center continues the practical spirit of Institute Professor Doc Edgerton, a pioneer in strobe photography, much beloved electrical engineering teacher, and co-founder of EG&G with two of his graduate students. The center concentrates on providing hands-on educational experiences for MIT undergraduates where they engage in challenging activities and projects in engineering and science.[209]

Together with the Public Service Center, the Edgerton Center runs an important set of Action Labs, what they call Service Learning, a teaching method that integrates community service projects into the curriculum, where students work on real projects, and each project serves a community in need.[210]

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[206] http://entrepreneurship.mit.edu/
[207] http://web.mit.edu/mitpsc/about/history.shtml
[208] http://web.mit.edu/mitpsc/
[209] http://web.mit.edu/edgerton/
[210] http://web.mit.edu/Edgerton/www/ServiceLearning.html

BioMedical-Enterprise Program (BEP) -- The Biomedical Enterprise Program (BEP) is a joint-program between the Harvard-MIT Division of Health Sciences and Technology (HST) and the MIT Sloan School of Management.[211] Through an integrated curriculum focused on the process of biomedical product development and commercialization in the healthcare sector. Participating students both develop their business analytic abilities and broaden their understanding of core physiological and emerging technology implications. While a young program, nearly a dozen participants have entered and several have won or been finalists in the MIT $100K Entrepreneurship Competition. Furthermore, BEP students co-founded and created the annual BioInnovations Conference at MIT Sloan.

Competitions

MIT $100K Entrepreneurship Competition -- The student-run MIT $100K Entrepreneurship Competition is "designed to encourage students and researchers in the MIT community to act on their talent, ideas and energy to produce tomorrow's leading firms."[212] Founded in 1989, as the $10K Business Plan Competition, by a joint-venture between the MIT Entrepreneurs Club (e-club) and the Sloan New Ventures Association (NVA). They teamed up to encourage combinations of engineering and management students, even then a natural combination, and to boost the visibility of their respective clubs. 64 proposals were submitted in the first year, with the winner receiving $10K, and $3K and $2K going to runner-ups. Both the deans from the MIT Sloan School of Management and the School of Engineering were founding sponsors, as were George Hatsopoulos, MIT alumnus and founder of ThermoElectron, and the Price Waterhouse entrepreneurial services firm. The Competition has run continuously since then, each year evolving and often adding new elements, for instance:

- in 1993, under Lead Organizer Joost Bonsen, going on the web, perhaps one of the very first entrepreneurship sites online.
- in 1995 adding Teambuilding Dinners and the first informal VentureFest alumni gathering

[211] http://bep.mit.edu/
[212] http://www.mit50k.net/about/

- in 1996, under Lead Organizer James Deverell, adding a Fall Semester Warm-up Round and boosting the prize fund to $50K, with $30K going to a Grand Prize winner and $10K each to two runner-ups.
- in 1997, under Lead Organizer Will Clurman, creating online submissions and dramatically growing the core team.
- in 1998, under Lead Organizer Sally Sheperd, MIT hosted the first conference for the organizers of business plan competitions, the annual MIT $50K Global Start-up Workshop (GSW)
- in 2000, Lead Organizer Elad Gil connected the $50K semi-finalists with the final reception of the first IdeaStream conference.
- in 2006, Lead Organizers Jason Fuller and Lawrence Walmsley grew the Competition to $100K prize fund by adding a Developmental Entrepreneurship & Social Impact track.

Lemelson-MIT Invention Prize -- Since 1995, the Lemelson-MIT Program, now based in the School of Engineering, has run several programs focused especially on encouraging invention and subsequent entrepreneurship. The on-campus centerpiece of this effort is a student-prize program which awards US$30K to "an MIT senior or graduate student who has created or improved a product or process, applied a technology in a new way, redesigned a system or in other ways demonstrated remarkable inventiveness."[213] Seven of the twelve inventor-winners are also entrepreneurs who have already founded companies to commercialize their inventions.

MIT IDEAS Competition -- Created in 2001 by Amy Smith of the MIT Edgerton Center and Sally Susnowitz of Public Service Center, the IDEAS Competition challenges members of the MIT community to develop creative ideas, "designs, plans, strategies, materials and mechanisms that benefit communities, locally, nationally or internationally."[214]

Several of the winners of the IDEAS Competition have gone on to prepare business plans and enter the MIT $100K Entrepreneurship Competition. Indeed, it was partly this demand which inspired the then MIT $50K Lead Organizers, Walmsley and Fuller, to

[213] http://web.mit.edu/invent/a-student.html
[214] http://web.mit.edu/ideas/www/about.htm

seek to double the prize fund and create a category especially for these developmental ventures with social impact.

Ignite Clean Energy (ICE) Competition by MIT Enterprise Forum -- In 2005, the Energy Special Interest Group (SIG) of the MIT Enterprise Forum of Cambridge, in collaboration with regional economic development and technology transfer partners, launched the first Ignite Clean Energy business plan competition open to participants Massachusetts-wide.[215] This Massachusetts-oriented Competition has since inspired MIT alumni and friends in California to launch a similar competition in Spring 2006, the California Clean Tech Open.[216]

Peer University Competitions -- Most greater-Boston area universities today run some kind of business plan competition, in several instances inspired by the visibility and success of the MIT $100K. Furthermore, since 1998, the MIT $100K Organizers have co-hosted the Global Startup Workshop (GSW)[217] for the organizers of business plan competitions in an attempt to reach out and help share best-practices in starting and operating similar competitions worldwide.

Myriad Student-Driven Venture Support Organizations

Throughout the Institute are at least a half-dozen student-run clubs specifically dedicated to technology-business, new venture development, company investment, entrepreneurial speakers, new technologies and products, and more.

There is a curious two-cultures phenomenon at play on campus, a disconnect between the science and technology elements of campus and the business elements. While they often realize they benefit from connecting with one another, they also use different vocabularies, value different things, and generally behave differently. Many of the informal, extracurricular mechanisms which are part of the entrepreneurial ecosystem were created or are in place to help bridge these cultures and connect those who most ought to know each other.

MIT Entrepreneurs Club (E-Club) -- The MIT Entrepreneurs Club (E-Club) was founded in 1988 by Peter Mui to rally technologist entrepreneurs. Peter had worked for Doc Edgerton for years and learned how important an intellectual community and

[215] http://www.mitforumcambridge.org/EnergySIG/IgniteCleanEnergy.html
[216] http://www.cacleantech.com/
[217] http://gsw.mit50k.net/

friendly curiosity are in supporting people with nascent ideas and bold dreams. Doc's attitude was "let's try it" and Peter brought this outlook to the weekly Tuesday evening E-Club meetings where everyone introduces themselves and gives a practice pitch about their new venture ideas, whether half-baked or fully-baked.

In 1989, Peter and colleagues Doug Ling and Richard Shyduroff launched the $10K business plan competition to boost the club's visibility. That same year, E-Club advisor Joe Hadzima began his IAP Nuts and Bolts of Business Plans as a non-credit, club-sponsored offering. In 1993, E-Club director Richard Shyduroff launched the first undergraduate seminar, the 6-unit High Tech Ventures at MIT, timing the class to begin at 7pm just after the regular E-Club meetings. The club continues today, largely focused on undergraduate and engineering majors, but open to many students visiting from Harvard and Babson, as well as alumni and friends.[218]

MIT Venture Capital & Private Equity Club (VCPE) -- The MIT Sloan-based VCPE was founded in 1995 by Monica Lee as the Venture MBAs, a team of venture capital-oriented MBA students who would take over running team-building dinners for students entering the then MIT $10K Entrepreneurship Competition. The VC club soon created the annual Venture Capital Conference in early-December, an activity that has grown to attract several hundred investment professionals and entrepreneurial students. More recently, students interested in the Private Equity realm of later-stage investments have expanded the scope of the club and run an annual Private Equity Symposium in mid-spring. The VCPE has been a potent force in cross-campus links, teaming up with the Deshpande Center to organize I-Teams class, and with VMS and SEBC to organize VentureShips, and more. The VCPE also runs speaker series, a VC Competition, and is instrumental in incubating emerging technology initiatives at MIT, including the first-ever MIT Energy Conference in 2006.[219]

MIT Science & Engineering Business Club (SEBC) -- Founded originally as the Biology Business Club, they soon generalized to Science and then also Engineering Business Club after peers in other departments asked to come to events. Within a year, the club was solidly established as a place where students studying science and engineering could meet peers and discover about careers in business.

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[218] http://web.mit.edu/e-club/
[219] http://www.mitvcpe.com/

Entrepreneurship is one major theme for the club (in addition to Banking and Consulting) and the principle vehicles for this interest are regular talks by entrepreneurs, an extracurricular unpaid internship program called VentureShips run with the Venture Mentoring Service, and an annual Technology & Entrepreneurship Conference (TEF) featuring prominent keynote speakers, emerging trend panels, live case example companies, and informal networking.[220]

MIT Sloan Entrepreneurs Club -- Founded originally as E-MIT, an entrepreneurship portal for all of MIT in 1999, the organization morphed into the Sloan Entrepreneurs in 2002 thus taking on the mantel of the Sloan New Ventures Association (NVA) which was founded in 1988 but went inactive in 1996-7.

Sloan Entrepreneurs hosts speakers, informal gatherings, and other events for the MBA entrepreneur community at MIT. Together with the MIT Innovation Club, they run the Iron Entrepreneur Competition, an annual informal competition to see who can propose a more creative new venture mini-plan in a brief period of time given identical materials, constraints and starting conditions. Perhaps the most important product for Sloan Entrepreneurs Club dues-paying members, is the Guide to all things entrepreneurial at MIT, an initiative started by club co-president Craig Rottenberg in 2003.

MIT Innovation Club (I-Club) -- The I-Club was founded in 2004 by Mike Osofsky and colleagues to rally students from around the Institute interested in invention and innovation. The Club "engages students, faculty, and the business community through interactive programs such as IdeaExchange brainstorms, Tech Testbeds, Innovation Experiments, and more." The I-Club was a founding co-creator of the I-Teams initiative now run as a joint-venture between the Deshpande and Entrepreneurship Centers.

More recently, the I-Club has launched a Digital Innovation Lab, connecting teams of students with corporate sponsors of research in MIT labs. This non-credit activity is a powerful example on intrapreneurship ideas and also touches on the important area of corporate venturing, bringing entrepreneurial and venture investment ideas to larger, more established firms.[221]

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[220] http://web.mit.edu/sebc/
http://www.mit-sebc.net/vteam/
http://web.mit.edu/sebc/tef/
[221] http://web.mit.edu/innovation/

Clubs & Extracurriculars Generally

The organizations formally or informally dedicated to supporting entrepreneurship are themselves only a subset of all the ways students connect with each other and are exposed to new venture links.

MIT TechLink -- TechLink was founded in 1999 as a joint-venture between the MIT Graduate Student Council (GSC), lead by President Luis Ortiz, and MIT Sloan Senate, lead by Executive Committee member Jack Busta, to connect graduate students across campus through informal social gatherings -- e.g. WineLink, JazzLink, InventLink -- lab tours, technology business talks, new student Welcome Parties, and more. TechLink also hosts regular LeaderLinks, gatherings connecting the student leaders of professionally-oriented and campus-wide clubs, people whose leadership skills and practical experience building and running volunteer organizations often finds future outlet in an entrepreneurial organization.[222]

Living Groups -- Each of the several dozen living groups at MIT has alums who have started companies. Some come back and encourage a new generation to try it as well. Brad Feld and several fellow VC alums from the Alpha Delta Phi (ADP) fraternity, for instance, organized and sponsored an off-campus retreat at MIT's Endicott House[223] called ADPrentice.[224] Over two days of talks, brainstorms, and a mini-business plan competition, the brothers connected with each other and the alums, all the while sharpening their venture skills. Other fraternities, sororities, and dormitory alums have done or are planning similar retreats and tangible engagements.

BioMedical Business Club -- Co-founded by multi-company founder Dr Carmichael Roberts in 1999 when he was in the MIT Sloan MBA program, the BioMedical Business Club generally caters to people interested in the business, leadership, and investment sides of the life-science, medical device, and healthcare sectors.[225] They host an annual BioInnovations Conference bringing together key players from "...industry, academia,

[222] http://web.mit.edu/techlink/
http://web.mit.edu/techlink/Pictures/web_album/index.html
http://web.media.mit.edu/~jpbonsen/LeaderLink-2003april.htm
[223] http://www.mitendicotthouse.org/
[224] http://www.feld.com/blog/archives/000656.html
[225] http://web.mit.edu/bbc

and government to discuss the next wave of innovations in life science technology, policy, and commercialization."[226]

Tiny Technologies Club -- Co-founded in 2001, the MIT Tiny Tech Club is an "institute-wide student organization which aims to advance understanding of emerging micro-through-nanoscale technologies, to serve researchers from throughout MIT through events and activities, and to build links between interested science, engineering, and business communities at and beyond the Institute." Tiny Tech organizes lab tours, holds talks, co-promotes a wide range of activities, and hosts informal TinyTech Dinner Talks connecting students, faculty, and visiting industry guests over a buffet-style meal.[227]

Energy Club -- Co-founded by MIT Materials Science doctoral candidate David Danielson in 2004, the Energy Club brings "together the energy technology, policy, and business communities at MIT"[228] Danielson and his colleagues saw a big gap at the Institute's offerings for people interested in energy technologies broadly. They created the Energy Club to host facts-driven conversations about energy challenges, introduce researchers to one another, and to connect in a substantive manner with industry at large.

Clubs Supporting Other Special Interest Domains -- Hobbyist clubs such as the MIT Electronics Research Society (MITERS) and the MIT Rocket Club or the Solar Car Club support inventive students who meet like-minded peers and these too spin-off new ventures. Culture clubs such as Club Latino or the European Club link compatriots who later go into business or collaborate on various projects. Professional-role oriented clubs such as Marketing[229] and Management Consulting connect students with practitioners and offer practical experiences through internships. And more. These examples just serve to illustrate that while the explicitly entrepreneurship-oriented student organizations are important, they are but one part of a vast distributed array of new venture connection and support activities at MIT.

Cross-Collaborations

There is a rich set of specific events and ongoing activities which are the joint-ventures or collaborations between student groups and Institute offices and programs. Some

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[226] http://web.mit.edu/bbc/bioinnovations/2006/index.html
[227] http://web.mit.edu/tinytech/
[228] http://web.mit.edu/mit_energy/
[229] http://web.mit.edu/marketingclub/

have been spotlighted earlier, including the MIT $100K Entrepreneurial Competition, which was created as a joint-venture between the MIT Entrepreneurs Club and then MIT Sloan New Ventures Association, and TechLink, a joint-venture of MIT Grad Student Council and Sloan Senate, and the IDEAS Competition, a joint project of the MIT Public Service Center and the MIT Edgerton Center. Many other small and large collaborations are crucial element of the Institute venturescape.

Enterprise Forum + $100K on Pitch'n'Polish & MidnightMadness -- For instance, the MIT Enterprise Forum of Cambridge (EFoC) was the founding host of the then MIT $10K Entrepreneurship Competition Final Awards Ceremony, a celebration of emerging student entrepreneurs held then in 10-250, one of the biggest lecture halls on campus. Today the MIT $100K Competition Finale is in the even-bigger Kresge Auditorium, but the EFoC continues to play a crucial role in running both Pitch'n'Polish (PP) and Midnight Madness (MM). PP helps inexperienced student teams refine their elevator pitches, a process which takes practice, editing, and more practice to sum things up quickly. MM coaches finalist teams for their presentation before the Judges.[230]

Enterprise Forum ICE + MIT Energy Club on Energy Week -- MIT Energy Week[231] is a "spotlight on the energy challenges that face us and the technologists, entrepreneurs and policy experts" who will help map a pathway forward. The MIT Energy Club coordinates with the MIT Enterprise Forum's Ignite Clean Energy Competition (ICE), the Presidents Office and the Lab for Energy and Environment on this week-long series of events featuring cutting-edge Institute energy research and entrepreneurial networking culminating in the MIT Energy Conference.[232]

Deshpande + Entrepreneurship Center on i-Teams -- Since 2003, the MIT Engineering School's Deshpande Center has collaborated with the MIT Sloan School's Entrepreneurship Center and the student-run Venture Capital and Private Equity Club to offer I-Teams, a project course where students assess the market opportunities and commercial potential of Deshpande-funded faculty research efforts.[233] This is one of the earliest examples of an Institute-wide elective course offering in entrepreneurship, one with formal course listing in departments of both the Engineering School and Sloan.

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[230] As described by Trish Fleming, EFoC Executive Director
[231] http://mitenergyconference.com/e_week.htm
[232] http://mitenergyconference.com/index.htm
[233] http://web.mit.edu/deshpandecenter/iteams/index.html

Others Collaborations -- The Deshpande Center has for several years now supported the SEBC in promoting and sponsoring a reception for the student-run Technology & Entrepreneurship Forum (TEF), a day-long conference spotlighting entrepreneurial MIT alums and encouraging the student startup ethos. In January 2006, the $100K Competition announced a parallel track on Developmental Entrepreneurship and Social Impact and ran several join events with IDEAS to promote student interest in international development and community service broadly. It is nearly impossible to document all the cross-collaborations since old ones whither and new ones blossom all the time. On the other hand, it is also nearly impossible to under-estimate how important such linkages are in weaving together the entrepreneurial fabric of MIT.

4.5 Technology Venture Zone Surrounding MIT Campus

Surrounding the MIT campus is a patchwork quilt of business parks and stand-alone office buildings and lab space which collectively form a Technology Venture Zone. MIT has been directly involved in this, first helping creating Technology Square, one of the first civic-academic partnerships to redevelop an abandoned old industrial zone, and later being instrumental in the Cambridge Center complex, University Park, and One Broadway.

Beyond these MIT-owned or institutionally influenced developments, are efforts by MIT alums including David Clem, whose Lyme Properties has independently developed over one million square feet of a "Science Park" near Kendall Square.[234] The Cambridge Center complex was developed by Boston Properties, co-founded by MIT alum Ed Linde.[235] Other nearby developments included One Kendall Square, One Memorial Drive, and more.

These structures and business parks all house a tremendous variety of companies at various stages of venture development from nascent startups through Global 1000 firms. A few industries are particularly highly concentrated, for instance, the biotechnology sector.

[234] http://www.lymeproperties.com/content.html
[235] http://www.bostonproperties.com/site/about/history.aspx

Several companies have also located their research branches in the area, in part to be proximate to the Institute. These include Mitsubishi Electric Research Labs (MERL),[236] Nokia,[237] Orange/FranceTelecom,[238] and Schlumberger.[239]

Local Biotech Cluster

Within one kilometer from campus are nearly one hundred biotechnology, medical device, and health-technology companies. Giants of the life-science sector such as MIT-spin-offs Genzyme, Biogen, and Amgen all have either headquarters or a major presence in greater Kendall Square. More recent startup companies such as BioScale, Codon Devices, Agrivida, AgaMatrix and others also made the area their founding home base. Finally, larger organizations have a research presence in the area, for example, Novartis Pharmaceuticals has located their world-wide biomedical research headquarters to be near MIT.[240]

Nearby Business Parks

Memorial Drive Research Row -- The area east of the original Main Group of buildings along the Charles River remained outside MIT hands until after WWII. During this time, the area became known as "Research Row" because of the density of technology-based firms. Arthur D. Little's headquarters, Electronics Corporation of America, Lever Brothers US HQ, the National Research Corporation (inventors of MinuteMaid frozen concentrate orange juice), and other companies occupied this stretch.[241]

Technology Square -- In the late 1950s, MIT partnered with the City of Cambridge to finance the acquisition of dilapidated old industrial buildings and create a modern business park called Technology Square, or Tech Square for short. The first phase was completed by the early 1960s and gave an indication of larger urban renewal projects to come. In the immediate neighborhood, for instance, came the Federally sponsored construction of facilities for a planned NASA research center. After President Kennedy's assassination, this center moved to Houston and instead the Department of Transportation Volpe research center moved in.

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236 http://www.merl.com/
237 http://research.nokia.com/locations/cambridge/index.html
238 http://www.francetelecom.com/en/group/rd/activities/vision/implantations/
239 http://www.bizjournals.com/boston/stories/2004/08/16/story4.html
240 http://entrepreneurship.mit.edu/biotech.php
http://web.mit.edu/newsoffice/2002/biotech-0828.html
http://web.mit.edu/newsoffice/2002/novartis.html
241 See Roberts

For years the original Tech Square buildings housed Polaroid and the separate MIT Lab for Computer Science (LCS) and Artificial Intelligence Lab (AI) along with the MIT-spin-off Draper Labs. After Polaroid fell upon difficult times and consolidated its campus in the Boston suburbs, a new owner of the complex was able to substantially add to the original footprint of buildings, nearly doubling the size to eight buildings with over 1.1 million square feet.

After long having no ownership stake in the complex, MIT acquired it in 2001 as a real estate investment. The Institute bolstered the ground-floor retail element of the buildings, and has invested heavily reconfiguring the buildings to be R&D lab space, in addition to offices. Tenants today include MIT labs in biological engineering and the Institute for Soldier Nanotechnology, as well as established firms such as Novartis, Dyax, and Forrester Research, and up-and-coming MIT spin-off companies such as Frictionless Commerce.[242]

Cambridge Center -- Cambridge Center is a large complex in Kendall Square bordering MIT on the opposite side of Main Street, running up to the edge of Technology Square, and adjoining the Volpe DOT research lab as well. MIT helped secure financing for the Center in the late 1970s and was very supportive of construction through the mid-1980s as a force for revitalizing Kendall Square. Today both the Whitehead Institute for Biomedical Research and the MIT-Harvard Broad Institute for Genomics occupy major buildings in Cambridge Center. The Center also is home to emerging growth MIT-spin-offs such as VANU Inc, a software radio firm, research labs, such as those run by Nokia and Intel, and major biotechnology firms, including MIT-spin-off Biogen Idec.[243]

University Park -- MIT originally acquired the old Simplex Wire and Cable manufacturing facility, north of west campus towards Central Square, in 1969 and began planning for its redevelopment through the 1970s. In 1983, the Institute teamed up with Forest City, a private concern who would manage and execute a multi-phase development plan on MIT's behalf.

This was not without local controversy. The City of Cambridge asked MIT to put development plans on hold, insisted on substantial mixed-income housing, and imposed other constraints and costs. Neighborhood residents protested the development plans

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[242] http://tech-square.com/default.htm
http://tech-square.com/html/tenants.htm
http://www.boston.com/business/technology/articles/2006/01/14/mit_to_put_complex_on_block/
[243] http://www-tech.mit.edu/V105/N12/kendal.12n.html

for years, culminating in a squatter campground dubbed "Tent City" By the late 1980s, the City had approved MIT's development proposal.

Over the last two decades the bulk of the 30 acre site has been built-out with nearly 2.5 million square feet of research and office buildings, residential and hotel space, parking, restaurants and retail areas, and several acres of parks and open space.[244]

Route 128 -- In the optimistic growth period following WWII, increased emphasis was placed on highway development. One enormous side effect was opening up a ring of real estate around Boston for development and ready commuter access. This became the original American high-tech area, preceding the boom development of Silicon Valley by several decades. Hundreds of MIT-related companies are located on Route 128, often moving there only after early founding days closer in-bound in the technology venture zone nearer to campus.[245]

One Broadway / Cambridge Innovation Center -- MIT acquired the old Badger engineering building after owner Raytheon decided to shift themselves to a suburban campus. The complex is run largely as a straight-forward real-estate holding, but one of the major tenants is an operation known as the Cambridge Innovation Center (CIC) founded and run by MIT Sloan alumnus Tim Rowe and colleagues. The CIC offers flexible office and light R&D space for emerging growth technology companies. They began as a combined incubation facility, linking real estate with venture investment, but soon separated these functions and have concentrated since on simply providing space and related business services. This has become one of the fastest growing real estate operations in Cambridge, and is the largest single tenant in the building occupying several floors, serving over 100 small business and emerging growth company clients, including several dozen MIT-spin-off companies such as ThingMagic, Adozu, Ambient Devices, and many more.[246]

4.6 Creative Innovation Networks Beyond MIT

In addition to the resources on campus or run by MIT people, there are dozens of useful industry groups, advisory firms, investment houses, and a web of other local, regional,

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[244] http://www.fceboston.com/portfolio_up_overview.asp
http://www-tech.mit.edu/V110/N3/upark.03n.html
[245] Saxenian, Lampe, Roberts
http://www.netvalley.com/archives/mirrors/sv&128.html
[246] http://www.cictr.com/

and other connections which fuel student, faculty, staff, and alumni entrepreneurship. In the decades since MIT President Compton co-founded ARD, the first formal venture capital firm, the greater Boston area has become home to hundreds of investment funds which have seed-and-growth financed thousands of ventures. This financial fuel has attracted a concentration of lawyers, accountants, marketing and PR folks, and the many other advisors young companies need as they grow up. These firms, in turn, are active in seeking out new business and make a point of sponsoring entrepreneurial events and activities at MIT (and other universities). This hunt for business through informal connections, vetted referrals, engagement in activities, and more are all crucial elements of the venture ecosystem at and beyond the Institute.

Part V

Relentless Renewal:

Distributed Initiative, Organizational Reinvention, and Emergent Faculty-Driven New Directions

Faculty interest -- and in turn the activities and explorations of students -- are what ultimately drive the Institute in new directions. Not all exploratory initiatives bear fruit to be sure, but the collective portfolio of all efforts does -- ultimately -- lead to new discoveries and promising early inventions.

Especially important in this context are the larger institution-building and direction-setting ambitions of the faculty. Everyone, at a minimum, pursues their own individual research agendae. Sometimes there is strength in numbers, however, and real benefit to banding together to form research initiatives, consortia, labs, centers, and more.

From this rich, highly distributed, largely bottom-up process comes emerging research themes which sometimes reinvent departments or labs, sometimes are the genesis of a new organization, and sometimes are quite embracive and cut across formal MIT departmental, school, and lab boundaries.

5.1 Hiring, Promotion, Tenure Key Mechanisms for Steering University

Universities change with relatively long time-constants. Newly hired junior faculty have five to ten years to ramp up and establish a scholarly track record before they face a tenure decision, a harsh up-or-out point. While many have questioned the centuries old practice of tenure -- what cynics call the granting of lifelong sinecure -- it nevertheless has a powerful hold on academia and forces a fairly far-sighted calculus on the hiring-and-promotion decision-makers.

Departmental peers and department-head, and then School Dean, and then Provost, and then Academic Council, and then President, and then ultimately the Corporation all have to agree on a tenure case before it is granted. This means an escalating series of comparisons where the scholarly track-record, and the prospective long-term productive and creative potential of faculty members are compared to internal and external peers. It is a remarkable gauntlet and perhaps only one fifth to one third of candidates are successfully tapped.[247]

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[247] Personal Guestimate

Given the highly distributed nature of the faculty and the self-directedness of research, it turns out that the hiring, promotion, and ultimately tenuring process are the single most powerful levers of Institutional direction and control. The Institute will become what the newly tenured faculty make it to be in 5, 10, 20-plus years, as they become the more senior academics, and decision-makers, and leaders of their respective labs, departments, and research institutions.

5.2 Emergent Faculty Interests & Ambition Steer the Institute

Future directions at MIT have sometimes been inspired top-down, and have very often been supported by current or past Presidents and other Institute leaders. But very rarely (if ever) has a research direction been imposed by a senior leader.

MIT Presidents have historically taken great pains to make it clear they will impose no vision on the Institute and that, instead, leadership and new directions emerge from the faculty ranks. MIT is what its faculty does, and the Institute goes where the aggregate research themes and fundraising ability of faculty take it.

Historically, relatively few faculty have the energy and ability and interest in starting, building, or growing research activities beyond their own individual research group. There are hurdles to overcome for a faculty member to initiate a new organizational direction. New research concepts or exploratory ideas are necessary, but by no means sufficient. Peers need to be sold on the core idea, sponsorship moneys raised, internal approvals negotiated and received (for instance, for space or proposal-slots or access to major donors), and more.

Since it is from the faculty that an aggregate Institutional direction flows forth, it is this emergent vision that lab directors and department heads and deans and senior officers seek to pull from faculty discussions and from promising explorations.

The Star Partnership (a.k.a. Feudal) Organizational Model[248]

Academia is strikingly analogous to the social order in feudal Europe or Japan, where faculty are the lords, dukes, knights and so forth, all with various degrees of influence, power, and rank. While faculty typically do not physically fight, they are nevertheless in contest, both internally at the university, and against rivals in other realms for money, people, and priority. While two or more lords may collaborate for a campaign or a

[248] Drawing from Diane Burton's terminology

season or even over a lifetime, the typical focus of a faculty member's attention is to themselves and their research group. The serfs and laboring peasantry of the academic realm are, of course, the students and staff, they too with their own hierarchies and perquisites.

The feudal analogy is not strict, however, in that position in academia is neither determined by heredity nor physical conquest, but rather by a peer-review promotion and tenuring process. Tenure is decided by senior faculty and administration and is intended to tap those up-and-coming scholars who have contributed dramatically to a field, differentiated themselves from colleagues, and appear to have a promising, fruitful, productive research future ahead of them.

Such a structure has tremendous advantages for the deep scholars, the archetypal faculty members who are pre-eminent in their domain. They have substantial autonomy over what they chose to work on, whom to hire, directions to move into, and with relatively few of the burdens of business or the managerial and organizational headaches of larger groups, joint ventures and more. It is true that some faculty do scale up their own research labs and manage through post-docs or research scientists. It is also true that some faculty take on organizational and institutional leadership roles as department head or lab director or dean. But relatively little in academic training and running a research group is direct preparation for running and growing an Institution. It is little wonder, therefore, that relatively few faculty chose to take on such roles and a non-trivial number of those who do end up either underperforming or overwhelmed and exhausted by the effort.

Most faculty -- all else equal -- would prefer to be left alone to concentrate on their favorite research topics. They have, of course, the basic burdens and expectations of being part of an academic enterprise: committee duties, giving talks, being part of fundraising junkets, writing proposals, editing journal articles, and much more. Plus faculty are endlessly invited to give special speeches or judge competitions or attend compelling events. And most commercially minded professors advise or are on boards of at least one or a few companies, startups as well as more established concerns. What is really remarkable is that they have any time to run their own research group, never mind teach and stay current in their scholarly literature (or have a family life).

Institutional Leadership and Lab Genesis as Orchestration

Running the Institute -- or for that matter a School, Center or Department -- is more akin to being a conductor of an orchestra than being a general of an army. Conductors orchestrate musicians who each are autonomous individuals and proud professionals. Generals, by contrast, boss soldiers through a chain of command and expect their orders to be followed. Of course, neither of those characterizations is complete: some conductors are quite dictatorial and the best generals lead more often through respect and trust than through fear and fiat.

Orchestration means drawing the best out of people, creating an ensemble which allows everyone to achieve their individual optimum while crafting a unique and wonderful whole. This is not easy. It requires taste and judgment, especially in selecting and promoting talent and in identifying, selecting, and pursuing research ideas and areas. An institution thrives or whithers by whether it attracts and hires new faculty (and students), inspires and encourages them to pursue bold and promising themes, and promotes and ultimately tenures the most vibrant and inspired and productive scholars.

Perhaps an even more challenging task is the birthing and sustenance of an entirely new research lab or organizational clustering. Money and other resources need to be found, people need to buy in and thus be sold on a new idea, and so forth. Furthermore, the burdens of being lab director are often above and beyond those of normal faculty duties.

Organization-building requires the integration of technical understanding and managerial skills. This is a relatively rare combination in academia; most faculty were selected for, and have been overwhelmingly rewarded for individual performance. It is by no means impossible, but definitely a happy accident when faculty are simultaneously interested and willing, as well as organizationally and managerially able, to start or run a lab.

A few case examples may serve to illustrate the spectrum of experiences, opportunities, challenges, and results achieved by contemporary lab founders and directors.

Whitehead Institute -- Biology Professor (and later Nobel Prize winner and CalTech President) David Baltimore recruited faculty and built the Whitehead Institute for Biomedical Research into the premier center for modern biology despite controversial funding and a unique relationship with MIT. Because of the demands of the donor, there was dissent within Biology faculty about the new organizational structure, unprecedented governance structure, and relatively unknown intellectual directions of the new

Institute. Baltimore persisted, overcame obstacles, and exercised good taste and judgment in hiring faculty and the best available junior scholars. The results to-date include great progress on the Human Genome project, the newly spun out Broad Institute, serving as a model for the newer McGovern and Picower Institutes in neuroscience, and more.[249]

Media Lab -- Architecture Professor Nicholas Negroponte and President-Emeritus Jerry Wiesner raised the money and secured Institutional commitment to create a new lab bridging the arts and engineering disciplines. Fueled by unprecedented amounts of industry sponsorship and a technology-savvy architect's touch, the new lab would prototype and invent the future of broadcast content, personal computing, and interpersonal communications. Negroponte and Wiesner overcame challenges, including resistance from LCS and AI faculty and antipathy from Architecture faculty, jealousy from less well financed parts of MIT, and defined a new collaboration environment, including an IP policy quite different from MIT norms. The resulting Lab has been a key driver of the media and information technology industry convergence, and subsequent creation of new sectors, with graduates influential in both academia and industry.[250]

Project Oxygen -- Lab for Computer Science (LCS) Director Michael Dertouzos, and Artificial Intelligence (AI) Lab Director Rod Brooks both sought a vehicle for expanding collaborations between their respective computer science dominated labs, for pursuing an imaginative vision of pervasive, human-centric computing, and for raising substantial sponsorship money from non-traditional sources. The resulting Project Oxygen wove together the research agendae of several historically disparate parts of both labs, proposing further research towards the systems themes of Hand- held or wearable devices, fixed- systems in our surroundings or Environmental systems, and the interconnecting Network, each labeled H21, E21, and N21 respectively. Industry sponsors included Acer, Delta Electronics, HP, NTT, Nokia Research, Philips Research, and by the Information Processing and Technology Office (IPTO) of the Defense Advanced Research Projects Agency (DARPA). Ultimately this joint-venture pursued several hundred solo and collaborative projects. While the two labs had operated as sometimes antagonistic independent entities for several decades, Project Oxygen enabled many practical research connections and built bridges between related fields

[249] http://wi.mit.edu/
http://wi.mit.edu/about/history.html
[250] http://www.media.mit.edu/about/index.html & Brand's story of Media Lab founding

and groups. When the move to the new Stata Center became imminent, this collaborative experience made it relatively easy on July 1, 2003 to merge the LCS and AI Lab into the combined CSAIL Computer Science Artificial Intelligence Lab.[251]

Picower Institute for Learning and Memory -- Nobel-prize winning Biology Professor Susumu Tonegawa became intrigued with the biological processes underlying learning and memory. In 1994 he secured financial support from the Fairchild Foundation, and soon thereafter ongoing support from RIKEN and NIMH, to bring together faculty and other researchers to look at brain function at several levels of analysis. In 2002, the Picower Foundation contributed substantial endowment financing to create physical facilities and scale-up this research group bridging biology and the neurosciences. In 2005, the Picower became one of the pillar tenants of the new neuroplex, a multi-lab building directly opposite the Stata Center on Vassar Street.[252]

Historic Bets on Disciplines

Departments are formed and changed much less frequently than new research labs and centers, perhaps 1/10th as often. President Compton wound down a couple less active departments in the 1930s in an effort to make way for new initiatives. But such moves are difficult and usually controversial. When Provost John Deutch and President Paul Gray decided to wind-down the Applied Biological Sciences department in 1988, there was tremendous hue and cry, largely because of the lack of consultation and opacity of decision-making.[253]

Nevertheless, the department was sorely in need of re-invention and renewed vigor. More recently, in 2004, a longer, more consultative and open procedure was followed by President Chuck Vest and Dean Tom Magnanti in merging Ocean Engineering department with Mechanical Engineering.[254] This too was controversial in some circles, but any observer could see the thoroughness of the review and assessment and ultimate decision.

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[251] http://www.oxygen.lcs.mit.edu/Overview.html
http://www.oxygen.lcs.mit.edu/publications/Oxygen.pdf
http://www.csail.mit.edu/index.php
http://web.mit.edu/newsoffice/2003/merge.html
[252] http://web.mit.edu/picower/
[253] http://www-tech.mit.edu/V109/N62/president.00n.html
[254] http://web.mit.edu/newsoffice/2004/merger-1208.html

Perhaps the biggest MIT bet in the past half-century was the concentration upon micro-biology at the Institute during the 1950-60s where investment, resources, and tenure-slots were shifted from the macro-disciplines of botany and zoology and instead committed to cellular and molecular biologists.[255] This was the beginnings of the genetic engineering revolution.

Faculty Research Portfolios & Cross-Financing

Faculty often have a portfolio of research projects ranging in status and type along several dimensions, including stage of development. For instance, some projects are more exploratory and bold, less certain of outcome and higher risk. On the other end of the spectrum are those further along in development, closer to completion. Often location on the spectrum correlates with the stage of study of the graduate student researchers in the faculty members group.

By having a range of projects, faculty are able to informally carve out a bit of funding from their other, better sponsored projects and "redirect" the moneys to some exploratory investigations. This is, of course, officially forbidden, but also seems to be -- anecdotally anyways -- a surprisingly common mode. Such projects are often too premature and perhaps too unbelievable to the traditional peer-reviewed funding sources. But without funding, there would be little or slow exploration.

5.3 Institute-wide Cross-Cutting Initiatives

Interdisciplinary collaborations are common at the Institute, and indeed, two faculty advising a graduate student can be just such a collaboration. And individual or project level integration between research, education, and extracurriculars is also fairly common. Rare and difficult, however, are large-scale collaborations or initiatives embracing more than a dozen faculty. Being federated together into research labs is an indication of common interests and shared community -- both quite important -- but mere co-location is not collaboration. Creating and growing multi-faculty labs or research centers is difficult enough.

Sometimes Institute-wide initiatives are initiated top-down, for instance the creation of a joint Harvard-MIT Division of Health Science & Technology by then President Jerry Wiesner and Provost Walter Rosenblith, or the chartering of an MIT Energy Research

[255] http://libraries.mit.edu/archives/mithistory/histories-offices/bio.html

Council by President Susan Hockfield, or the initiation of the Computational & Systems Biology Initiative (CSBi). Other times, cross-cutting efforts have their roots in educational initiatives which in turn spillover into other domains, for example the impact of the Project Athena, spearheaded by then MIT Engineering Dean Gerald Wilson and Professors Steven Lerman and Jerome Saltzer. And still other programs are pulled together by National Emergencies, for instance, the WWII Radiation Lab perfecting radar, Ripe Opportunities, for example, the post-WWII RLE successor to the Rad Lab, pressing Industrial Challenges, for instance, the IMVP manufacturing and productivity study, and Student Initiative, for example, the MIT $100K Entrepreneurship Competition.

Historic Institute-wide Initiatives

Radiation Lab & RLE -- World War II inspired enormous government investment in R&D to solve wartime problems. Perfecting RADAR was near the top of the list for early warning of attack dramatically changes the prospective outcomes in battle. MIT became the home of the Radiation Lab which took the British microwave generator and improved it for practical use in ground, water, and airborne radar units. This effort required materials people, electrical engineers, mathematicians, physicists, and many other disciplines to cross-collaborate. The lessons learned from this WWII lab inspired the founding of the Research Lab for Electronics (RLE), the prototypal interdisciplinary research lab.[256]

Health Science & Technology -- Instead of creating stand-alone MIT Medical School in the 1970s, President Wiesner and senior Institute leadership chose a collaborative university joint-venture between Harvard and MIT, with emphasis on Harvard's Medical school and cutting across multiple schools at MIT, but with special focus on Science, Engineering, and Management.[257]

Project Athena -- MIT together with founding sponsors DEC and IBM launched Project Athena in 1983 as a 5-year attempt to build a scalable, distributed, campus-wide computing platform capable of supporting and connecting 10,000 or more high-end workstations. After a three-year extension and high student usage rates, the system was integrated into MIT's informations systems operation and became a basic expected service for anyone on campus.

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[256] http://www.rle.mit.edu/
[257] http://hst.mit.edu/

One founding reason for Project Athena was to encourage greater integration of computing into the undergraduate educational experience, something which turns out to have taken much longer than anticipated but today pervades the Institute. Some of the successful outcomes of Project Athena were anticipated at the beginning -- for instance, the Kerberos computer network authentication protocol.[258]

But some of the most striking results were entirely emergent from widespread actual use and student-driven experimentation and adoption. Fast stable email and access to high-quality "free" laser printing were significant attractors. Furthermore, the fact that students could login at any workstation, anywhere, at any time and have rapid access to all their files and communications was a liberating experience. The Zephyr system was one of the first, if not the first widely used instant messaging system[259] and lead students to engage in a new way of communicating.

One of Project Athena's most enduring results is that it is an existence proof of the usefulness of a technology testbed where distributed user-driven innovations could bubble-up. Athena was a powerful predictive microcosm where anyone could witness emergent usage patterns and literally see the future first. Indeed, two decades after Project Athena was initiated, nearly everyone on the internet has Athena-equivalent functionality: we all can get our mail, find files, message one another, view information graphically, crunch numbers, and more.[260]

International Motor Vehicle Program -- As part of a wider effort to understand productivity, technological innovation, social impact, and more, a cross-disciplinary team was formed in the late 1970s to look at the global automotive industry, one of the largest on Earth. Drawing upon talent from all five schools, the International Motor Vehicle Program "has mapped lean methodologies, established benchmarking standards, and probed the entire automotive value chain", an effort resulting in multiple books, several hundred working papers, and substantial influence on industry practice.[261]

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[258] http://web.mit.edu/kerberos/ & http://en.wikipedia.org/wiki/Kerberos_protocol
[259] http://en.wikipedia.org/wiki/Comparison_of_instant_messengers
[260] http://en.wikipedia.org/wiki/Project_Athena
http://www.research.ibm.com/journal/sj/313/ibmsj3103I.pdf
http://ocw.mit.edu/NR/rdonlyres/Electrical-Engineering-and-Computer-Science/6-933JThe-Structure-of-Engineering-RevolutionsFall2001/CD345739-32D8-4BF2-BB23-35111CCCC944/0/final.pdf
[261] http://imvp.mit.edu/pubarcindx.html & http://imvp.mit.edu/

MIT $100K Entrepreneurship Competition -- The MIT $100K Entrepreneurship Competition was born in 1990 with a US$10,000 grand prize for the most compelling business plan prepared by MIT students that year. This joint-venture between the MIT Entrepreneurs Club and MIT Sloan New Ventures Association, grew over time to become an autonomous extracurricular entity running dozens of events in support of a Fall and Spring semester competition attracting over 150 entries and reaching over a thousand students at the Institute. The prize fund has grown first to US$50,000 and again in 2006 to US$100,000. The scope of the Competition has also grown to embrace students from all five Schools and almost all departments at MIT. Over the first 15 years, the Competition alumni went on to found nearly 100 new ventures with an aggregate market valuation exceeding several billion US dollars.

This entrepreneurial initiative emerged from and has been grown and developed overwhelmingly by student and alumni volunteer activity. Deans Kerrebrock and Thurow of Engineering and Management gave crucial founding support and moneys and an institutional home for the activity, but the persistence and initiative of the students were central to its growth and ongoing success. From the very beginning the Competition has been open to all, undergraduate or graduate student and from any program or department. (In contrast with similar competitions at peer schools which have limitations and constraints on eligibility.)[262]

Emergent MIT-wide Initiatives

Computational & Systems Biology Initiative (CSBi) -- Computational and Systems Biology draws upon faculty from multiple departments in both the Schools of Science and Engineering and is one of the first examples of a "virtual center" where faculty remain in their current labs and departments, but extra effort is applied to raise research funds, craft new classes, build up a doctoral program, create a shared infrastructure and instrumentation base, and more.[263]

International Development Forum (IDF) -- International Development efforts are MIT are quite fragmented but some unifying forces are at play, including the International

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[262] http://www.mit50k.net/
[263] http://csbi.mit.edu/

Development Forum (IDF) which has for 5 years woven together all willing participants Institute-wide who pursue global development.[264]

Energy Research Initiative (ERI) -- At her inauguration, MIT President Hockfield introduced "a major new Institute-wide initiative on energy. This initiative will foster new research in science and technology aimed at increasing the energy supply and bringing scientists, engineers, and social scientists together to envision the best energy policies for the future. We will seed this initiative with resources for new interdisciplinary faculty positions."[265]

Communications Futures Program (CFP) -- In 2000, the MIT MicroPhotonics Center (MPC) began an Microphotonics Roadmapping project along with industry partners. All were motivated by the usefulness of the semiconductor roadmapping project spearheaded by Sematech. Such an industry-wide, multi-technology initiative allowed competitors to meet in a neutral forum and discuss issues and general business challenges in a mutually beneficial manner. The MPC would thus help companies chart a course for the future and plot out promising pre-competitive, collaborative research projects.

MPC Director Professor Kim Kimerling connected with MIT Sloan Professor Charlie Fine, who in turn led the effort to generalize from just the microphotonics-specific sector to looking at communications-related labs MIT-wide and craft a more industry-wide value-chain roadmap (VCRM).

This more general interest lead Fine and colleagues to propose and form the multi-lab Communications Futures Program (CFP), which would "define the roadmap for communications and its impact on adjacent industries" all in partnership with "companies across the entire communications value chain including end users." The hope was to achieve the benefits of coordination in an industry with little vertical integration and yet interdependent technology, industry, and regulatory policy dynamics.[266]

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[264] http://web.mit.edu/idf/
[265] http://web.mit.edu/erc/
[266] http://mphotonics.mit.edu/
http://mph-roadmap.mit.edu/
http://cfp.mit.edu/

Campus-as-Laboratory

- **Sustainable Campus Energy Initiative** -- The Energy Initiative faculty subcommittee on "walking the talk" led by Professor Vladimir Bulovic proposed that the MIT campus be a "model teaching and research tool, a place [students and faculty] can affect and improve, an energy-conscious place." They are proposing a Sustainable Campus Energy Initiative to increase campus energy efficiency, take a leadership role among peer universities, and tap into student activism and creativity to drive this sustainability agenda.[267]
- **Emissions Remediation Testbed** -- Already, the MIT co-generation facility, for instance, was the testbed for a new emissions remediation technology developed by GreenFuel, an MIT-related startup. The GreenFuel bioreactor uses single-cell algae and photosynthesis to consume carbon dioxide and nitrogen oxides emitted by the plant. GreenFuel then harvests the resulting biomass for use as raw material or biofuel. This early proof-of-concept on a real power plant has helped the company scale up its operations, target larger customers, and attract top-tier venture capital investment.[268]
- **LivingTheFuture (LTF)** -- LivingTheFuture is a campus-as-lab initiative in much in the same spirit as Project Athena, only wireless. As currently proposed, LTF is a "five-year research program that will define and prototype the future of mobile, personal communications. It will use the MIT campus and surrounding community as an observatory for the future, by providing a staged series of open wireless communication and computing platforms on which the entire MIT community can invent, reflect, and iterate the future of personal and ubiquitous communications."[269]

5.4 Envisioning New Directions

Investments today in nascent areas are, in effect, bets on future directions. Out of a portfolio of such bets, promising results inspire further investigation and investment, and this process cycles onward. Sometimes structural change in labs is needed to revitalize

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267 http://web.mit.edu/erc/campus/index.html
268 •http://web.mit.edu/newsoffice/2004/algae.html & http://www.polarisventures.com/NewsEvents/
269 Whitepaper Proposal, Trossen, et al 2006 http://web.media.mit.edu/~jpbonsen/MIT-Project-Mercury.htm

an area. Project MAC split into both the Lab for Computer Science and Artificial Intelligence Labs in the 1960s and then merged back together in the early 2000s, both arguably healthy moves given the research opportunities, sponsor circumstances, and collaborative forces of the moment.[270]

At other times, entirely new directions emerge, usually inspired by one of several forces: emergent ideas from below, where students or faculty or others provoke a new domain, for example, that of Wearable computers in the Media Lab, or Drug-Delivery MEMS in Chemical Engineering. Sometimes, macro challenges inspire research, for instance the Environment area or Energy Technology sectors. Very influential are often sponsorship and finance driven directions. For instance, when the Army supported the Institute for Soldier Nanotechnologies, several chemists at MIT realized they have long been "nanoscientists" and stepped forward to partake in the funding.

Most faculty are deep experts and highly opinionated in their own areas. Perhaps too rarely do they step back and discuss their broad areas of commonality or future directions of mutual interest. Periodically, however, faculty do rally together in retreats. By brainstorming together, the faculty better build off the projects and ideas that their peers are proposing.

All told, these processes are not easy. Renewal is anything but easy. Protagonists are faced with challenges on nearly every level and on nearly every front. A huge fraction of faculty time, for instance, is spent with proposals and sponsors instead of actually doing research, a tremendous source of frustration, especially in times of flat or shrinking traditional sources of sponsorship. Perhaps the single greatest drivers of enduring Institutional success, therefore, are a healthy endowment, a source of internal capital, and longer-term sponsor commitments, multi-year agreements with foundations and industry which grant a degree of stability and allow for longer-term planning and action.

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270 http://www.csail.mit.edu/events/news/labmerger.html

Part VI
Future Frontiers:
Emerging MIT Research Themes

To capture the totality of all trends and directions Institute-wide, from historical through the present and into the future, would be a monumental (and perhaps impossible) task. Nevertheless, a few specific case "Future Frontier" areas especially stand-out.[271] These cases are differentiated by the scale of action and the predominant level of technological analysis (and often by methodological disputes), but are all unified by the intensity and boldness with which scholars are pursuing these emergent frontiers, and the promise of what lies over the horizon.

These emergent MIT research themes include:

- **Tiny Technologies** -- the analysis and synthesis of ever more sophisticated structures, functions, and systems at length scales ranging from micro-through nanometers.
- **Systems Biotechnology** -- the analysis (and ultimately synthesis) of complex biological phenomena, processes, pathways, and systems.
- **Neurotechnology** -- the discovery (and ultimately design) of neurological sensing and control functions, and the development of neuro-diagnostics and therapeutics.
- **Systems Sociology** -- bringing engineering tools and methods to the analysis (and potentially synthesis) of complex, real-world social and socio-technical systems.
- **Global Innovations** -- understanding root causes and developing deep, distributed, sustainable solutions to the most pressing and persistent problems of humanity worldwide.

[271] There are several alternative ways to frame a handful of top areas at MIT. For instance, a more disciplines approach is represented in the MIT Matrix http://web.media.mit.edu/~jpbonsen/MIT-Emerging-Technology-Matrix.htm and the MIT Engineering Dean Magnanti is fond of the Big O's http://web.mit.edu/deshpandecenter/portfolio.html

6.1 Tiny Technologies

The Tiny Technologies embrace a growing number of approaches to analyzing and building ever smaller-scale structures and systems whose characteristic and functional features range in size from micro-through nanometer.

Pathways to Ever Smaller Systems Building

Many people in the modern era of small-scale systems engineering were inspired by MIT alumnus and CalTech Professor Richard Feynman's visionary and imaginative speech "There's Plenty of Room at the Bottom" given on December 29th 1959 at the American Physical Society at CalTech.[272]

Since Feynman, scientists, engineers and tinkerers have taken a variety of approaches to ever smaller-scale synthesis. Mechanical Engineers often emphasize Precision Engineering, crafting ever more precise manipulators, fine tuned systems with increasingly exotic tolerances. Materials Scientists especially emphasize self-assembling materials systems. Silicon wafer fabricators take the massive infrastructure of the semiconductor industry and craft Micro-Electro Mechanical Structures (MEMS). Chemists emphasize catalysts and often draw lessons from natural processes, for instance photosynthesis or cellular energy conversion.[273]

Micro-thru-Nanoscale Research

Today the Institute has ongoing TinyTech efforts in a dozen major labs, centers, and departments.

Within the Microsystems Technology Lab,[274] several hundred students, staff, and faculty explore and fabricate complex electronics, MEMS structures, photonic devices, employing a growing variety of specialty coatings, materials, and treatments.

The Lab for Molecular Self Assembly[275] and various self-assembled materials initiatives, are pursuing a 'bottom-up' approach to material assembly molecule by molecule and increasingly atom by atom to synthesize novel larger-scale structures.

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[272] http://www.zyvex.com/nanotech/feynman.html
[273] http://pergatory.mit.edu/ & http://web.mit.edu/lms/www & http://web.mit.edu/chemistry/www/faculty/nocera.html
[274] http://mtlweb.mit.edu/
[275] http://web.mit.edu/lms/www/

The Army-funded Institute for Soldier Nanotechnology (ISN),[276] supports a broad range of projects all with the shared goal of improving the defensibility and survival of future soldiers and others wearing extreme-condition gear.

The Materials Science Department hosts the NanoMechanical Technology Lab,[277] for testing and probing living cells, polymers, "bioceramics, optoelectronic materials, surface coatings, and metals" for mechanical behavior at the nanoscale.

The MicroPhotonics Center[278] supports interdisciplinary academic and industrial collaboration in the basic science and pre-competitive development of applied microphotonics.

Furthermore, several exploratory proposals are underway urging research in nanobiology, nanotechnology applied to nerve regeneration and medical therapeutics more generally, micro-and-nanotechnology applied to energy conversion and more.

Differing Approaches

The Tiny Technologies represent a collection of different approaches to synthesizing and exploring ever smaller scale systems. In several fields researchers have recombined techniques or repurposed instrumentation all to fruitful ends. But disagreements persist among the most powerful approaches to back. For instance, capital equipment intense MEMS fabrication or desktop soft lithography. Or top-down precision mechanical engineering approaches versus bottom-up biological engineering. Or microorganism-based synthesis versus materials-based self-assembly. The concert of these approaches makes sense and researchers are pursuing all of them and, in some instances, combinations of these approaches.

6.2 Systems Biotechnology

Systems Biotechnology is the analysis (and ultimately synthesis) of complex biological phenomena, processes, pathways, and systems and represents the "How To" engineering approach applied to the classic "What Is" interests of the life scientists.

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276 http://web.mit.edu/isn/
277 http://web.mit.edu/nanolab/
278 http://mphotonics.mit.edu/

Cross-Cutting Approaches to Engineering of Biology

Several themes are emerging at MIT bringing engineering methods to bear on the classic life sciences. Increasingly robotics and automation have made experimentation a combinatoric affair, with massive numbers of experimental variations happening in parallel. This work has been driven by novel instruments (and has in turn inspired development of those instruments). The vast quantities of data involved have lead to growing fields of bioinformatic and genomic analysis, including increasing mathematical and statistical sophistication. The systems-outlook is leading to a growing effort to computationally model life systems at various levels of analysis and abstraction.

On the technological fringe has been the growth of the synthetic biology outlook. The synthetic biologist is unusually interested in constructing novel systems. At the very least, they hope to craft some new functional or behavioral mode by recombining and manipulating biological components and organism-systems.

This is the outlook of an engineer: one who tinkers, builds, assembles, and really wishes to figure out "How" as their overriding project goal. This is neither better nor worse than the interests and outlook of a scientist: one who observes, seeks exceptions, looks to rule out hypotheses or explanations, and really wishes to understand "Why" as their overriding project goal.

A synthetic biologist is someone who engineers with biological substrates. This is in contrast with many branches of Biological Engineering whose faculty are, in fact, scientists who ardently use tools in pursuit of discoveries. In many ways the synthetic biology outlook is alien to them, much like the early electrical engineers were alien to the physicists.

Bio, Systems, and Engineering Activities

Interest in biological engineering lead to forming a cross-disciplinary division at MIT with faculty jointly appointed with traditional departments in Engineering and Science. In 2005-6, the division was given departmental status, with Course number 20 and authority to grant undergraduate majors.

Curiously, MIT President Karl Compton and colleagues argued for the formation of a combined Biology and Biological Engineering discipline in 1936-9,[279] an amazingly far-

[279] http://openwetware.org/images/0/09/MITBioE1939.pdf &
http://libraries.mit.edu/archives/mithistory/histories-offices/bio.html

sighted exhortation. Soon, however, the scientists came to dominate and the department was renamed just Biology.

Today systems biology and the engineering approaches to biology increasingly pervades multiple departments, including Civil, Mechanical, Materials, Electrical, and Chemical. Each of these traditional engineering disciplines has an approach and interest in the broad realm of biology.

The Whitehead Institute for Biomedical Research recently spun out the Broad Institute for Genomics,[280] a joint Harvard-MIT center seeking to accelerate fundamental understanding of widespread illnesses.[281]

The Computational and Systems Biology (CSBi) is an interdisciplinary effort to systematically analyze complex biological phenomena with emphasis on mathematical methods and sophisticated measurement methods and devices.[282]

Placing Bets, Concentrating Resources

To pioneer new directions, individuals and institutions have to place bets and go with them over time in the face of fear, uncertainty, and doubt. Doing all approaches, all at once risks diluting each effort into irrelevancy. When MIT bet biology should be molecular biology in the 1950s, the classic botanists, zoologists and other traditional life scientists were unhappy. Their approaches were deliberately starved of funding and as those faculty retired (mandatory at 65 years then), they were not replaced directly. Instead slots were filled by people pursuing the new approach. Furthermore, MIT committed additional faculty positions to the new approach and thus built up a concentrated community of modern biologists whose pioneering work lead to the genetic engineering revolution and biotechnology business sector.

Today, the nascent department of Biological Engineering faces similar challenges issues of resource concentration. Should it be a broad assemblage of faculty grounded in various engineering disciplines applying themselves to a widely scattered set of interesting life science questions. Or should the department place a bet on nascent but promising emerging approaches, for instance on Synthetic Biology. If not at MIT, this is likely to happen elsewhere.

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280 http://www.broad.mit.edu/
281 http://www.broad.mit.edu/about/history.html
282 http://csbi.mit.edu/

6.3 Neurotechnology

Many labs and departments at MIT are pursuing different aspects and approaches to Neurotechnology, the emerging concert of neuroscience and neuroengineering, including the discovery (and ultimately design) of neurological sensing and control functions, and the development of neuro-diagnostics and therapeutics.

Integrative Neurothemes

The computational tools of today, electromechanical probes, experimental sophistication and more are such that historically intractable clinical challenges are within reach. Artificial senses, nerve regeneration, hybrid neuro-muscular electrodes and many more highly applied neuro-engineered systems and more.[283]

A growing number of MIT students and alumni have founded or are founding and building companies to commercialize Neurotechnologies. Established firms such as MIT Professor Emeritus Ray Badour's Amgen[284] has bought Immunex and is deploying Novatrone indicated for reducing neurologic disability due to Multiple Sclerosis. Emerging companies, such as Shai Gozani's NeuroMetrix[285] are commercializing neuromuscular diagnostics; MIT HST Professor Richard Cohen's Cambridge Heart[286] ships noninvasive cardiac diagnostics which can predict ventricular tachyarrhythmias associated with sudden cardiac death. If the neurotechnology frontier progresses forward along current trend lines, we are at the beginnings of a wave of neurodiagnostic and neurotherapeutic products and ventures to come.

Brain Scholarship and Early Impact

The School of Science, Biology and Brain and Cognitive Science each have faculty seeking fundamental understanding of neural development and brain function. MIT Labs actively involved in this domain include MTL, RLE, HST, AI, CBCL, BCS, McGovern, Whitehead, Picower, Martinos, and more.[287] MIT is continuing to invest a tremendous amount in the neuroscience infrastructure, including the creation of a new neuroplex housing the Picower and McGovern Institutes as well as the Brain and Cognitive Science department (BCS).

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[283] http://www.eecs.mit.edu/grad/areavii.html
[284] http://www.amgen.com
[285] http://www.neurometrix.com
[286] http://www.cambridgeheart.com/
[287] http://web.mit.edu/newsoffice/nr/2000/neuromit.html

In the School of Engineering, Mechanical Engineers, Materials Scientists, Electrical Engineers, Chemical Engineers, Biological Engineers, and more, investigate neuromorphic computing, artificial intelligence, prostheses, motor-control systems, and neuroengineering generally.[288] Engineering research themes include neuroimaging and diagnostics, psychophysiology measurements, rehabilitation feedback, affective computing, neurotherapeutics, surgical tools, neuropharmaceuticals, deep brain stimulation, prosthetics and neurobionics, artificial senses, nerve regeneration, and more, and ultimately the creation of synthetic neurosystems.

Neuro- Science vs. Engineering?

While there has been decades (if not centuries) of engineering interest in the mind -- in fields ranging from basic electricity to bionics and prosthetics, brain imaging, surgical tools, artificial intelligence, and more -- the majority of contemporary research investment, lab construction and new hires have been in the sciences and most especially in the neurobiology and brain and cognitive sciences. Curiously, while all other scientific departments now have at least one parallel engineering department, neuroscience does not. For instance, Mathematics has Computer Science; Physics has Mechanical, Electrical, and Nuclear Engineering; Chemistry has Chemical Engineering; Earth, Atmosphere and Planetary Sciences has Civil and Environmental Engineering; and Biology now has Biological Engineering. The closest parallels to BCS are an amalgamation of bio-electrical engineering, the health science and technology program, nuclear imaging. It remains to be seen how much MIT leadership prioritizes neuroengineering as a complement to the neurosciences.

6.4 Systems Sociology

Much like Systems Biology engages engineers and computer scientists in the traditional life sciences, Systems Sociology is an emerging research movement which brings engineering approaches to bear on the classic social sciences -- especially the tools and methods of computation and modeling, instrumentation and automation, iteration and experimentation.

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[288] http://hst.mit.edu/nerc/

Emerging Socio-Themes

MIT has a growing number of efforts bridging across our schools and disciplines to develop broad excellence in this promising domain and pursue social policy experiments, complex systems modeling, technology testbeds and other Innovation Observatories, and more.

An new generation of interdisciplinary social scientists are bringing classic scientific and engineering methods to bear on social systems. Clinical trials and controlled-experiments are practices drawn from the pharmaceuticals sector and the wetlab. Iterative or combinatoric approaches hail from the automation-savvy engineering disciplines. Collectively these are becoming a form of experimental sociology. Experiments in social settings, however, require seemingly intractably large numbers of people in various groups and settings, controlling for demographics, background, and myriad other factors. Classic observational approaches can not scale to capture enough essential sociometrics, the relevant measures of behavior or activity or circumstances.

Essential to this endeavor, therefore, is the growing use of ever more powerful and mobile socioscopes, instruments for observing people in day-to-day social settings. Socioscopes are the broad class of instruments which social scientists can use to observe people in real-world circumstances under ever more natural conditions with ever greater data-fidelity. By analogy, when Galileo and fellow astronomers sought the stars, they created and used telescopes. When Leeuwenhoek and fellow biologists sought cells they created and used microscopes. Lemelson-MIT Invention Prize-winner Leroy Hood was inspired by his mentor William Dreyer to "always practice biology at the leading-edge; and if you really want to change biology, develop a new technology for pushing back the frontiers of biological knowledge."[289]

Indeed, when the modern sociologists seek previously intractable or un-visible social phenomena and "push back the frontiers", they too need to develop new technology, they need to create and use socioscopes. Especially powerful as socioscopes are re-purposed consumer electronics with built-in sensing, computing, and communications infrastructure -- for example, mobile phones or PDAs. People already willingly carry phones everywhere. With a bit of programming and user instruction and proper IRB

289 http://web.mit.edu/Invent/n-pressreleases/n-press-03LMP.html

humans-as-experimental-subjects approvals, phones will become increasingly powerful tools.

These socioscopes and data from other innovation observatories will lead to a vast volume of sociometric data, which is increasingly driving development of socioinformatics, the analytic and visualization tools to help scholars understand and mine for patterns.

These data and lessons will, in turn, inspire more systematic sociodynamic modeling of the relevant social system and problem domain in an effort to find further hypotheses for testing. Such tests are the realm of experimental sociology and increasingly of Synthetic Sociology, the use of computer games, virtual microworlds (e.g. SimCity),[290] and management flight simulators (e.g. The Beer Game)[291] as artificial social systems where human role-players simulate various levels of social system and highly distributed massively multi-player games create a synthetic society. Such a society is fair-game for a systems sociologist. And the computer and network mediated environment is ideal for iteration, controls, systematic interventions, repeat trials, and other elements of the experimental method.

Complex Social & Technological Systems Research

Emergent work in systems sociology is happening throughout the Institute. The data-and-analysis driven Engineering Systems Division researchers are dealing with ever more complex socio-technological systems and refining new methods and helping shape and evolve a new discipline. The Sloan School includes a large contingent of systems dynamics, financial modeling, experimental marketing, and behavioral methods researchers. The Department of Economics Poverty Action Lab employs randomized trials to assess poverty-alleviation practices, a form of experimental sociology.[292] Media Lab device and tool builders are increasingly collaborating with social scientists to understand human dynamics, negotiation and sales effectiveness, the role of affect in education, and more. Anthropology faculty are using group-ethnography to scale up their ability to capture rich social phenomena. Computer Science faculty are pursuing projects in the realm of computational politics. Faculty in Comparative Media Studies

[290] http://simcity.ea.com/about/inside_scoop/sc_retrospective.php
[291] http://beergame.mit.edu/
[292] http://www.povertyactionlab.org/

and Logistics and Business are all using simulations and games as tools to teach. And much more.

Controversy & Skepticism

Classic social scientists sometimes view instrument-laden, math-happy, engineering-like activity with skepticism, disdain, or worse. While it might be "nice" to collect all that data, they say, it is impossible to fully appreciate the analog richness of human systems and to discern underlying meaning and so forth. Sometimes they simply are comfortable with the classic small-scale cottage-industry nature of their work, with time-tested vintage tools and labor-intense methods and thus resist change.

But as with modern molecular biologists, a growing number of modern social scientists are being inexorably drawn into socio-experimentation at ever-larger scales, using socioscopic instrumentation of increasing sophistication, mining enormous datasets with ever more powerful socioinformatics tools, and seeking to understand such systems through various systems modeling methodologies. Researchers may disagree with the particulars and they certainly will specialize in an area or an approach, but they are likely to be swept along by the broadly new systems sociology wave front.

6.5 Global Innovations

There is rich vein of interest at the Institute in understanding root causes and crafting solutions to the most pressing problems of humanity, including energy and the environment, water and utilities, communication and transportation, educational and financial services, healthcare and hope.

Integrative Focus on Giga-Challenges

While most of the research at MIT has some ultimate application or relevance everywhere on earth, the initial applications or appreciation of the work has traditionally been in rich countries, the so-called First World. And yet, three-quarters of humanity live beyond first world borders and in developing regions. Furthermore, some of the most pressing issues humans face are in the most impoverished areas. Access to energy, communications, healthcare, and so forth are all vital giga-challenges, issues affecting over a billion people each.

Although MIT generally urges "service to humanity" most traditional research orientation and direct impact has, in practice, been in wealthy countries. Of course, there are deep international roots at the Institute: civil engineering of waterworks in Africa, sanitary engineering and the early development of environmental engineering, rich connections in planning and architecture throughout Asia, helping found the IIT system in India, and many other connections are evidence aplenty of global Institute reach. But only relatively recently has there been an increasingly coherent wave front of research and educational interest in all things global at the Institute.

Solving these global giga-challenges requires a concert of methods, including cross-cutting approaches drawn from the other emerging sectors at MIT, including the Tiny Technologies (e.g. solar energy materials), Systems Biotechnology (e.g. SARS biodiagnostics), Neurotechnology (e.g. Suspicion Engine security systems), and Systems Sociology (e.g. clinical trials of anti-poverty policies).

Global Systems Research and International Development Efforts

Especially over the past five years, interest and action on Global Innovations has blossomed at the Institute. Such international development innovations are about solving problems faced by those beyond first-world borders. MIT is increasingly emphasizing innovation everywhere in large part driven by grass-roots student action and emphasizing entrepreneurial approaches to dissemination, for instance the Water and Sanitation projects explored by MIT Sloan students in Global Entrepreneurship Lab (G-Lab).[293]

The MIT Energy Initiative is a newly launched campus-wide effort to "tackle the world's energy crisis through science, engineering and education"[294] and build upon the work of a dozen labs and departments, including the Lab for Energy and Environment and Departments of Electrical, Chemical, and Nuclear Engineering.

MIT faculty were among the founders of sanitation engineering, a pioneering element of what today is part of Civil and Environmental Engineering (CEE).[295] Current CEE work on Water and Sanitation includes deep focus on Nepal and other emerging regions.[296]

Research on the environment and on global changes is occurring within the Center for Global Change Science[297] and the MIT Climate Modeling Initiative.[298] Since 1997, MIT

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293 http://entrepreneurship.mit.edu/glab/
294 http://web.mit.edu/erc/
295 http://www.chemheritage.org/women_chemistry/health/richards.html
296 http://web.mit.edu/watsan/
297 http://web.mit.edu/cgcs/www/

has been a joint-venture partner with three other universities in the Alliance for Global Sustainability (AGS) addressing the challenging and complicated "intersection of environmental, economic and social" forces.[299] The Earth System Initiative (ESI)[300] rallies together faculty interested in systems perspectives on terrestrial issues, with special focus on evolutionary processes and human impacts

Throughout the life science disciplines and labs such the Whitehead, Broad, focused initiatives in Chemistry, EECS, Media Arts and Science, and Biological Engineering, faculty are pursuing deep understanding of viral, bacterial, and genetic ailments, crafting diagnostics for early assessment, and striving to create vaccines and other therapeutics.

MIT has had long-time interest in K12 educational research and outreach, with dozens of programs[301] and several focused research projects, for instance in education and technology at the Media Lab,[302] and a teacher education program.[303]

Institute faculty have also had long connections to tertiary schooling. Faculty and MIT Presidents have helped found Stanford, CalTech, IITs, Birla Institute, and many other important organizations. Most recently, the Institute has placed materials for hundreds of courses online via OpenCourseWare, a pioneering effort to create a "free and open educational resource for faculty, students, and self-learners around the world."[304] MIT also focuses on teaching-the-teachers and has, for instance, since 1996 run the MIT-China Management Education Project where Chinese faculty visit MIT, participate in MBA courses, and can incorporate these experiences in their own curricula and programs back home.[305]

Development Economics is one of six main research areas in the MIT Economics Department[306] and is the domain for substantial field research. In 2003, department faculty launched the Jameel Poverty Action Lab (J-PAL)[307] to improve the effectiveness of anti-poverty programs through use of randomized trials, much like pharmaceuticals are tested with clinical trials.

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298 http://paoc.mit.edu/cmi/
299 http://globalsustainability.org/
300 http://web.mit.edu/esi/
301 http://ideas.mit.edu/~pscadmin/
302 http://llk.media.mit.edu/
303 http://education.mit.edu/
304 http://ocw.mit.edu/index.html
305 http://mitsloan.mit.edu/globalmitsloan/china.php
306 http://econ-www.mit.edu/about/de.htm
307 http://www.povertyactionlab.org/

The International Development and Regional Planning (IDRP) Group in Urban Planning[308] focuses especially on economic development, regional and urban planning, labor and industrial policy, public and civic finance, infrastructure development, and poverty-alleviation policies and programs.

Much of the work at MIT in global outreach has been coordinated since 1952, by the Center for International Studies (CIS),[309] a cross-disciplinary effort connecting over fifteen percent of the MIT faculty. CIS supports programs addressing arms control, human rights, migration, urbanization, and more. One major outreach initiative is MISTI, the MIT International Science and Technology Initiative, which for over a decade has sent students on study-and-work experiences to eight different countries.[310]

Globalization Projects within the Industrial Performance Center (IPC)[311] are investigating offshoring, the structure and emergence of local and regional innovation systems, and most generally on the macro-phenomenon of globalization.

The International Development Initiatives (IDI)[312] actively engages students as designers of products and systems which solve pressing community needs.

Beyond these formal research and degree programs are hundreds of specific classes taught by the faculty and literally dozens of MIT student extracurricular efforts in international development.[313]

Divergent Directions & Differing Global Visions

Especially in areas where results are hard to directly measure, vast disagreements about approach persist over decades. Environmental impact assessment, development aid policies, and other domains have consumed trillions of dollars over decades with regrettably little enduring impact.

Many researchers at MIT continue to view global development challenges as things "we have already solved" in rich countries and that it is thus up to governments and businesses to work on the deployment problem. And yet, huge areas of endeavor – for example, health diagnostics, clean energy, robust telecom -- all require tremendously

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308 http://web.mit.edu/dusp/idrp/index.html
309 http://web.mit.edu/cis/
310 http://mit.edu/misti/
311 http://globalization.mit.edu/
312 http://web.mit.edu/idi/
313 http://web.mit.edu/idf/

sophisticated approaches and represent an unsolved frontier. Furthermore, those civic and commercial institutions are themselves subjects for further research and innovation since they indeed often are the bottleneck limiting societal gains.

Other disagreements seem more ideologically grounded, for instance the social justice scholar may think very little good can come from entrepreneurial business methods. Or development aid economists may lament the lack of institutional investment in telecom infrastructure and thus be blind to the fast-spreading bottom-up village phone entrepreneurial business model.

While scholars may disagree on methods or simply pursue different approaches and even frame their end-goals in unique ways, all at MIT are broadly unified in their quest to understand and ultimately solve the most pressing issues facing humanity.

Conclusion

MIT is a wonderful living example of an Innovation Institute, a place where creative inquiry leads to real-world impact. From the core learning-by-doing ethos, through long-time connections with industry, integration of the Research-Education-Extracurriculars Triad, entrepreneurial support systems, and relentless institutional re-invention, the Institute is a concert of creativity.

And yet tremendous challenges lie on the horizon:

- The MIT campus is physically, economically, and politically constrained and limited in Cambridge, Massachusetts. Can the Institute continue to thrive without room to grow or freedom to physically reconfigure?
- Research and education are increasingly expensive -- partly due to the nature of the required equipment, partly due to environmental and regulatory burdens -- and yet traditionally dominant Federal sponsorship is stagnant or shrinking.
- Competition for moneys and talent keeps growing. Even if the Institute remains a uniquely dense concentration of greatness, other institutions are of increasingly higher quality and seek slices of the same sponsor pie.
- International and especially Asian universities are among the greatest competitive threat. They are in geographic areas with tremendous economic vitality, strong pro-education policies and cultures, hardcore work-ethics, and substantial population growth.

And yet these challenges can also be viewed as opportunities:

- Perhaps it is time to go beyond one physical campus or begin combining with other institutions or otherwise geographically hedging bets.
- Since growth of US Federal moneys is stalling, there is great practical incentive to connect further with industry, foundations, individuals, and overseas sources of sponsorship as well as encouraging greater budgetary prudence at home.
- Maybe the Asian emergence represents an opportunity for more intense joint-ventures and cross-collaborations, possibly even mergers creating some kind of World Institutes of Technology (WITS).

There remains much to be studied about MIT. Much of the Institute's detailed history, the subtleties of internal operations, and thought-processes of key leaders still remain poorly captured and characterized. For instance, we have some sense of the currently operating laboratories, but we know very little about the many more labs which faculty considered and proposed, but were ultimately stillborn or stalled or squelched. We know of the fundraising success-stories, but relatively little about the how and why of missed-opportunities. We recall too little about the chances MIT had to be a leader in a scientific or engineering sector, but lost out to rivals. We have relatively little objective evidence about the pros and cons of the tenure system. And we have little comparative understanding of MIT practices in contrast with those of peer universities and research organizations.

Most generally, the envisioning, financing, and orchestration of new research directions remains a vast and complex terrain, one we have only been able to survey in a macroscopic fashion here. More work remains in capturing higher-resolution quantitative data about historic and current practices; in modeling and simulating the emergence, growth, and re-invention process of faculty, labs and departments; in doing long-term longitudinal studies of researcher, lab, and departmental transformations over time; in systematic observation and simultaneous comparison of research theme emergence at several institutions; and so forth.

What is especially compelling about MIT is that it is a place of extraordinary effectiveness, an outlier on the distribution of all organizations, and a place which, in turn, attracts and concentrates together outliers on the bell curve of human ability selecting from a nearly world-wide talent pool. The colossal challenges facing humanity necessitate that all extraordinarily effective people and organizations discover knowledge and invent solutions at a faster pace than ever, for they are perhaps our best chance at achieving timely results. Better understanding of how things work at the Institute, of how to maximally improve, and how to best share and replicate elsewhere are, therefore, of paramount importance to our future as a people and as a planet.

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