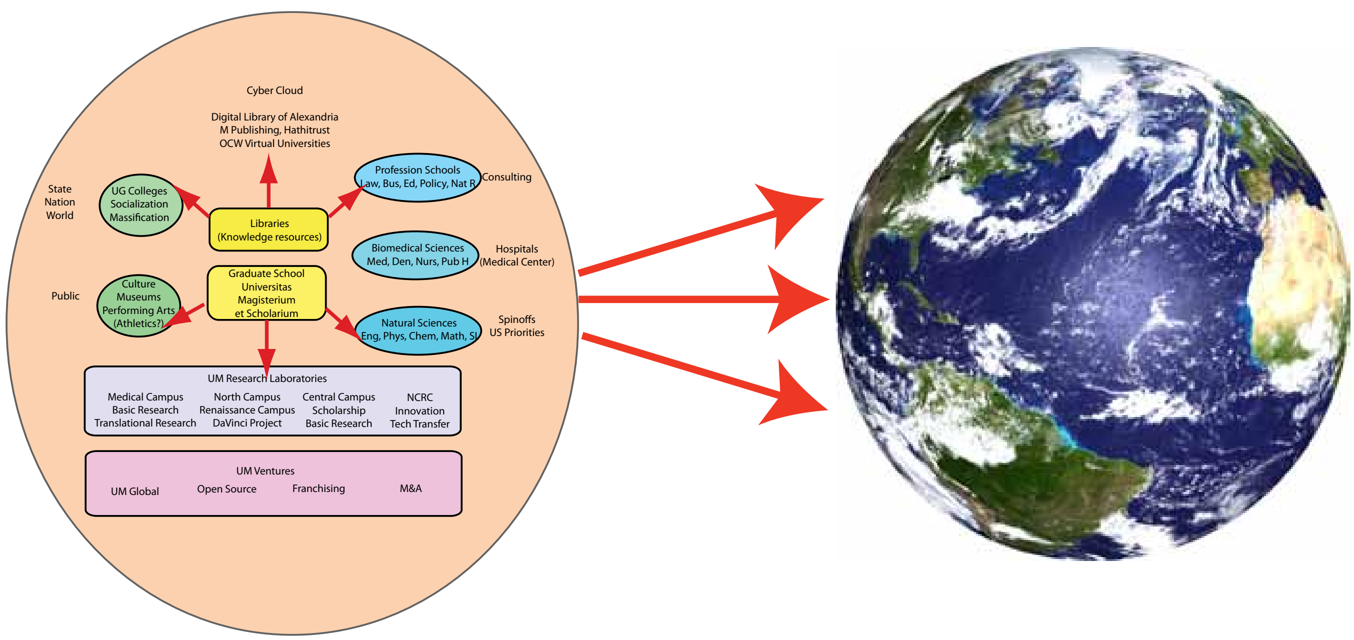
When Michigan Changed the World!



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Prologue

Three times in its recent history, the University of Michigan has actually changed the world through the efforts of its faculty and its research and teaching that developed tools remarkably similar to those that created our modern civilization in purpose and impact.

Universitas (enabling new "unions" of people)

In the Middle Ages new social structures began to appear, first triggered by the role of the church, not so much because of its religion, but because of its creation of organizations such as monks and the communities of workers necessary to construct great cathedrals. Latin served as the common language to enable the communication necessary to bring people together. Events such as the Crusades exposed Western Europe to the Islamic cultures of the East, and by the 13th Century, the guilds and cities necessary for trade and commerce were formed.

By the 14th century, schools and universities appeared to train citizens for the evolving civilization. Great teachers such as Peter Abelard of Paris and Irnerius of Bologna were attracting scholars from across Europe to form learning unions consisting of masters and scholars, or in Latin, *Universitas Magistrorum et Scholarium*, the foundation of today's universities.

Of course, resources for communicating and building "universitas" or unions have steadily evolved since Medieval times, through transportation (roads, ships, railroads, automobiles, planes,…) and communication (e.g., sign language, pony express, telegraphs, telephones, television,...). But the unprecdented pace of evolution of digital technology, increasing in power roughly 100 to 1,000 fold a decade, has created entirely new forms of communication, from e-mail to video transmission to immersive environments (virtual and augmented reality). But the most profound impact has been through the Internet, built by a consortium led by the University of Michigan with IBM and MCI in the 1980s and 1990s and supporting software such as the Worldwide Web, which has made this form of communication truly available on a global level. New "universitas" structures have appeared such as collaboratories (first developed by a consortium led by Michigan), social media, and broader exploration of the impact of "cyberinfrastructure" technology, again led by several of the University's faculty.

Renaissance (providing access to knowledge to meet the needs of society…including its creativity)

While the medieval university provided the model for higher education, first in Europe, then in North America, and eventually throughout the world, it was largely a bystander to the great intellectual movements of the 15th and 16th century: the Renaissance and the Reformation. (Lohmann, 2002) The medieval universities held fast to the traditions of scholasticism, both in philosophy and pedagogy.

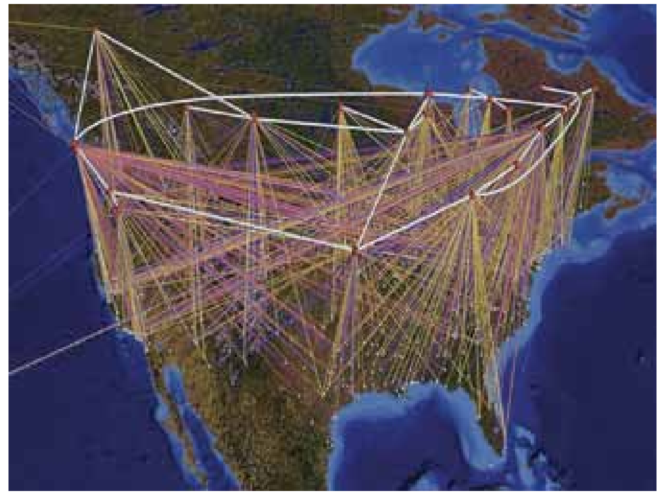
Emerging from 14th century Florence, the discovery by scholars of many ancient texts in their original Latin and Greek and led to the appearnance of *humanism*, the study of human nature and worldly topics rather than religious ones. Renaissance humanists believed that the "liberal arts" (art, music, grammar, rhetoric, oratory, history, poetry, using classical texts, and the studies of all of the above) should be practiced by all levels of "richness". They stressed the importance of self, human worth, and individual dignity rather than religious dogma. As the printing press replaced medieval manuscripts with printed books, humanism moved from being an Italian phenomenon into being a European movement. Scholasticism, the Inquisition, superstition, and feudal society were decisively changed through the revolutions of the 17th and 18th centuries. (Haskins, 1957)

Although the printing press enabled the distribution of knowledge through books and libraries, these objects had limited access (constrained by cost, location, languages, etc.) But by the early 1990s, the digitization of written material became both affordable and available (through the evolution of intellectual property laws). The Mellon Foundation took an important step through the support of the JSTOR project enabling the University of Michigan to digitize and provide Internet access to large numbers of history and economics books. The implications of such projects to create "digital libraries" available to millions of scholars stimulated the University of Michigan to broaden its School of Library Science to include information technology in its curriculum, becoming the nation's first School of Information, focusing on the production of "informationists" capable of guiding searches in cyberspace rather than simply librarians managing books. The University, working closely with IT companies such as Google (with the massive Google Books digitization project), universities (with the even larger HathiTrust digital library consortium), and Internet organizations such as Wikipedia, helped to enable millions of people to interact to access, modify, and create new knowledge on the Internet. This collection of digital knowledge resources and applications would acquire the name "cyberinfrastructure"). The access to this knowledge "in the cloud" has triggered a *renaissance* of creativity.

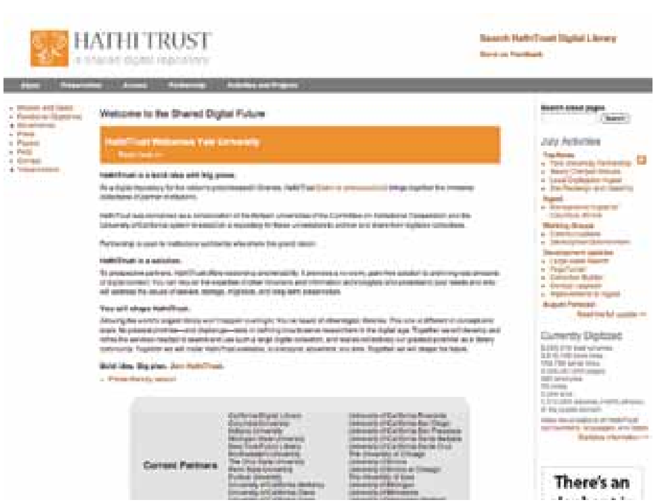
Enlightenment (providing not only access to the existing knowledge of the world but as well the learning necessary to use it to create new knowledge).

The intellectual movement of the Enlightenment, emerging in the early 18th century, had great impact on universities as scholars as not only created new knowledge, but learning begin to take on new forms such as the sciences to enable it to not only spread about the globe and trigger major social change. Although the Enlightenment idealized the concepts of democracy and republic from Greek and Roman civilizations, scholars such as John Locke interpreted these as implying that citizens held certain natural rights such as life, liberty, and property, and that governments derived their existence from the consent of the governed and their duty to protect these rights. The Enlightenment created a strong movement for a general improvement in human life,

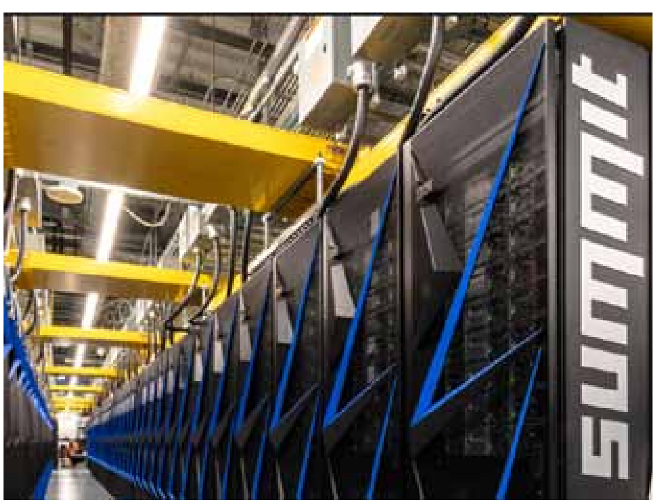
A new paradigm for the university appeared that would eventually dominate Europe: the *research university*. This approach was built on the belief that the function of the university should be broadened beyond learning to include scholarship, the creation of new knowledge itself. While this provided the model for today's universities, any vision proposed for the university's future must consider the extraordinary changes and uncertainties of a future driven by exponentially evolving information and communications technology. The great connectivity provided by the Internet already links together the majority of the world's population. To this, one can add the emerging capacity to capture and distribute the accumulated knowledge of our civilization in digital form and provide opportunities for learning through new technologies such as augmented and artificial reality, collaboratories, and intelligent tutors. Universities will be key, but they must invest in new resources combining not only the traditional learning goals of the curriculum but also the creative spirit of the arts and sciences. They must both serve and adapt to an emerging global society no longer constrained by space, time, monopoly, or archaic laws and instead even more dependent upon the elements of a new Enlightenment based upon reason, science, humanism, and progress.



Universitas: From UM's Computer Aided Engineering Network (CAEN) to NSFNET to the Internet



Renaissance: From the HathiTrust to Collaboratories (UARC)



Enlightenment: From Supercomputers, to Centers for creating and applying the news tools of technology

Chapter 1

Leaders and Best

The University of Michigan clearly qualifies for inclusion in the small group of institutions that have shaped American higher education. Although premature for a frontier state, in the 1850s its first president, Henry Tappan, proposed a vision for the University of Michigan that enabled it to become the first American model of a modern university, adapting the European (von Humboldt) model of rigorous seminars and advanced scholarship based on the tradition of high intellectual standards in the arts and sciences.

The young University of Michigan built one of the first observatories in America for astronomical research. Michigan was the first university to build and operate its own hospital. Beyond undergraduate education, it was among the first American universities to develop professional programs such as medicine, public health, business, and engineering. From its founding, the University of Michigan has always been identified as one the most progressive forces in American higher education.

Michigan has long defined the model of the large, comprehensive, public research university, with a serious commitment to scholarship and service. It has been distinguished by unusual breadth, a rich diversity of academic disciplines and professional schools, social and cultural activities, and intellectual pluralism. This unrelenting commitment to academic excellence, broad student access, and public service continues today. In virtually all national and international surveys, the university's programs rank among the very best, with most of its schools, colleges, and departments ranking in quality among the top ten nationally and with several regarded as the leading programs in the nation. The late Clark Kerr, the president of the University of California, once referred to the University of Michigan as "the mother of state universities," noting it was the first to prove that a high-quality education could be delivered at a publicly funded institution of higher learning. (Kerr, 1963)

Although most new arrivals to the campus sense that the University of Michigan is a large public university with unusually strong quality, they would not necessarily conclude that this was a place where the practice was to attempt to change the world. Of course, from time to time a newcomer arrives with the hope of harnessing this gigantic academic institution to do just that!

A Tradition of Leadership through Pathfinding and Trailblazing

Beyond academic excellence and unusually broad educational opportunities, one more element of the Michigan character seems particularly appropriate during these times of challenge and change in higher education. It is certainly true that the vast wealth of several of the nation's elite private universities–e.g., Harvard, Yale, Princeton, and Stanford–allows them to focus investments in particular academic areas far beyond anything that Michigan or almost any other university in the world can achieve. They are capable of attracting faculty and students of extraordinary quality and supporting them with vast resources.

Yet Michigan has one asset that these universities are rarely able to match: its unique combination of *quality*, *breadth*, and *scale*. This enables Michigan to take risks far beyond anything that could be matched by a private university. Indeed, because of their relatively modest size, most elite private universities tend to take a rather conservative approach to academic programs and appointments, since a mistake could seriously damage a small academic unit. In contrast, Michigan's vast size and breadth allows it to experiment and innovate on a scale far beyond that tolerated by most institutions, as evidenced by its long history of leadership in higher education. It can easily recover from any failures it encounters on its journeys along high-risk paths.

This ability to take risks, to experiment and innovate, to explore various new directions in teaching, research, and service, defines Michigan's unique role in American higher education. In fact, beyond academic leadership, from time to time the University actually does something that changes the world! For example, it was the first university to own and operate its own hospital, thereby combining the medical training and research conducted by its faculty with the clinical care offered by its hospitals. It introduced the new discipline of aeronautical engineering within a decade after the Wright Brothers' flight and nuclear engineering only a few years after the Manhattan project. In the 1950s Michigan conducted the clinical trials to verify the success of the Salk Vaccine. Astronauts trained at the University led NASA missions to the moon in the 1970s. And in the 1980s, Michigan joined with IBM and MCI to build, lead, and manage the Internet, a role it continued to play well into the 1990s.

Put another way, throughout its history, both the University of Michigan–through, of course, its students, faculty, staff, and alumni–do BIG Things! In fact, every once in awhile, Michigan does something that truly changes the world! Some of these achievements are listed in the appendix to this chapter.

In fact, one might well make the case that in an era of great change in society, Michigan's most important role has been that of a *pathfinder* and a *trailblazer*, building on its tradition of leadership and relying on its unusual combination of quality, capacity, and breadth, to reinvent the university, again and again, for new times, new needs, and new worlds.

Whether through academic innovation (e.g., the quantitative social sciences), social responsiveness (e.g., its early admission of women, minorities, and international students), or its willingness to challenge the status quo (e.g., teach-ins, Earth Day, and the Michigan Mandate), Michigan's history reveals this pathfinding and trailblazing character time and time again. When Michigan won the 2003 Supreme Court case concerning the use of race in college admissions, the general reaction of other colleges and universities was "Well, that's what we expect of Michigan. They carry the water for us on these issues." When Michigan, together with IBM and MCI, built NSFnet during the 1980s and then expanded it into the Internet, this again was the type of leadership the nation expected from the university.

However, continuing with the frontier analogy, while Michigan has a long history of success as a pathfinder, trailblazer, and occasional pioneer, it has usually stumbled as a settler, that is, in attempting to follow the paths blazed by others. All too often this leads to complacency and even stagnation at an institution like Michigan. The University almost never makes progress by simply trying to catch up with others.

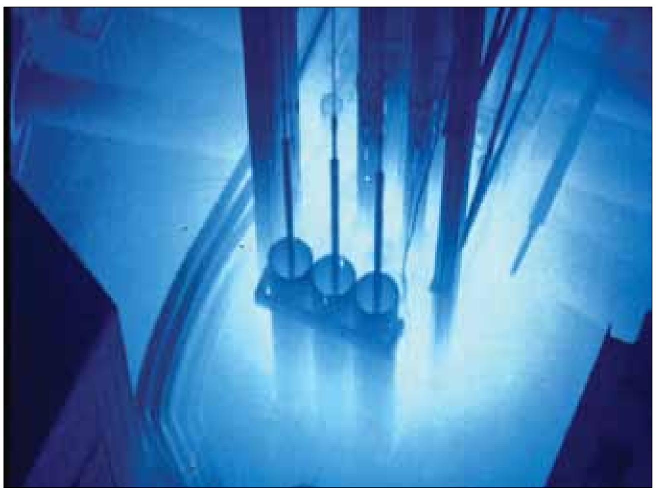
Michigan travelers in Europe and Asia usually encounter great interest in what is happening in Ann Arbor, in part because universities around the world see the University of Michigan as a possible model for their own future. Certainly they respect—indeed, envy—distinguished private universities, such as Harvard and Stanford. But as public institutions themselves, they realize that they will never be able to amass and focus the wealth of these elite private institutions. Instead, they see Michigan as the model of an innovative university, straddling the characteristics of leading public and private universities.

Time and time again colleagues mention the "Michigan model" or the "Michigan mystique." Of course, people mean many different things by these phrases: the university's unusually strong and successful commitment to diversity; its hybrid funding model combining the best of both public and private universities; its strong autonomy from government interference; or perhaps the unusual combination of quality, breadth, and capacity that gives Michigan the capacity to be innovative, to take risks. Of course, all these multiple perspectives illustrate particular facets of what it means to be *the leaders and best.*

But perhaps most of all, one marvels at the University's capacity to do "big things" that sometimes change the world. To illustrate, we have provided a "brief" list of several of these contributions (although its takes up four pages!)

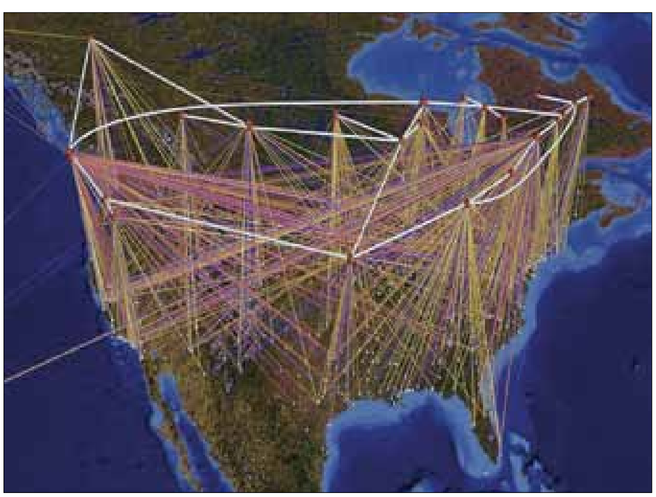
Announcing the success of the Salk polio vaccine

Kennedy's Peace Corps speech at Michigan

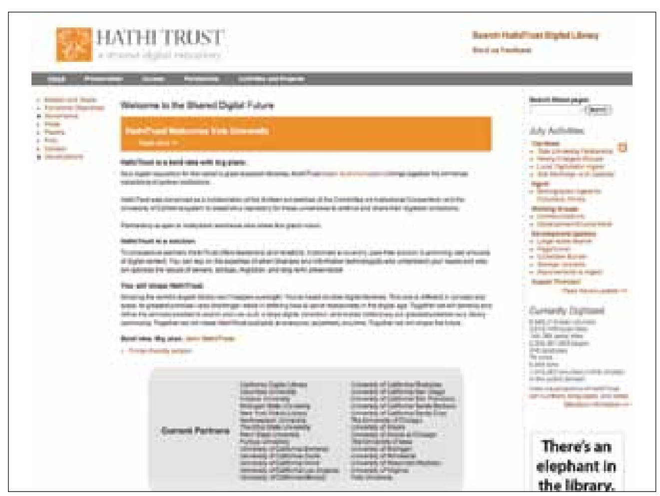


The world's first academic programs in atomic energy

Apollo 15, the UM mission to the moon (with a car!)



Joining with IBM and MCI to build the Internet



Creating the world's largest digital library

Michigan is one of the few universities capable of changing the world.

UM Does Big Things!

Ways in which the University of Michigan
has changed the world

(1817) Catholepistimead or University of Michigania (in Detroit with Michigan Territorial Land Grant)

(1837) University moves to Ann Arbor; Michigan achieves statehood.

(1845) Alpha Epsilon chapter of Chi Psi Fraternity: first fraternity house in the nation.

(1850s) First effort to build true university in America similar to those emerging in Europe (von Humboldt), secular in character with a balance between teaching and research, as evidenced by the construction of the Detroit Observatory, the third largest observatory in the world (Tappan)

(1856) First university building designed and equipped solely as a chemical laboratory

(1859) First university to introduce moot courts in law curriculum

(1860s) First university to own and operate its own hospital

(1868) Alumnus Joseph Beal Steere, naturalist, explorer, educator; set off in 1870 on a five-year exploration around the world where he discovered many previously unknown species of flora and fauna

(1869) Alumnus Charles F. Brush earned recognition as the "Father of the Arc Electric Lighting Industry" for his many inventions

(1870s) Created secondary school system (Henry Frieze)

(1870) The first large university to admit women.

(1871) Introduced the seminar method of teaching

(1873) Alumnus John Harvey Kellogg developed and advocated the eating of a dry breakfast cereal, from which came the flaked cereal product that led his brother to found the famed Kellogg cereal brand in 1906

(1870s-1890s) Developed and taught the first courses in new disciplines such as bacteriology, forestry, meteorology, sociology, modern history, journalism, and American literature, modern languages, pharmacy, speech, forest administration, sanitary science, science and art of teaching

(1880s) One of a handful of early leaders in the reform of U.S. medical education

(1880s) Leadership in introducing new disciplines of engineering: naval architecture, marine engineering (1881), aeronautical engineering (1916), automotive engineering (1913), transportation engineering (1922)

(1893) Alumna Alice Hamilton , a specialist in lead poisoning and industrial diseases, was known as the "Mother of Industrial Health." Her work led to a state law requiring medical examinations and various safety procedures in the workplace

(1900) Moses Gomberg, U-M professor of chemistry, discovered organic free radicals

1900s: Microbiology: development of culture techniques for parasites and spirochetes (Frederick George Novy)

(1905) Built the first naval architecture towing tank and model basin.

(1915) First degrees in public health (together with Harvard)

(1915) Alumni E. C. Sullivan and H. W. Hess, invented in 1915 several new forms of glass, including Pyrex, "Daylight Glass" and chemical-resistant glassware, which helped relieve shortage of German-made glassware during Word War I

(1919) The first student union (the Michigan Union)

(1924) Development of iodized salt to wipe out endemic goiter (David Cowie)

(1929) First courses in data processing

(1920s and 1930s) Summer physics conferences on quantum mechanics

(1930s) Development of electrocardiogram or EKG (Frank N. Wilson)

(1931) Created the first Alumni University

(1934) First Bureau of Industrial Relations

(1939) Development of plan for voluntary health insurance (Nathan Sinai)

(1940s) William Dow led Allied scientists in the design and construction of a 125-ton jamming device used to disable German and Japanese radar systems.

(1944) Development of influenza vaccine for U.S. Army (Thomas Francis, Jr.)

(1945) Bureau of Public Health Economics established in UM School of Public Health as primary source of archival information on medical care

(1940s) Alumnus Kelly Johnson, working for Lockheed, he established the legendary Lockheed Skunk Works and created the P-38, the F-104, the U-2 and the SR-71 Blackbird during a remarkable 40-year career.

(1940s) James V. Neal discovery that defective genes cause sickle cell anemia

(1947) Own and operate a large commercial airport (Willow Run Airport)

(1950s) First university program in peaceful uses of atomic energy Michigan Memorial Phoenix Project)

(1950s) First degree program in nuclear science and engineering

(1950s) Developed first major programs in quantitative social sciences (Survey Research Center)

(1958) Built and operated the largest nuclear reactor on college campus (2 MW Ford Nuclear Reactor)

(1960s) Lawrence Klein developed econometric models (Nobel Prize)

(1950s) William Beierwaltes developsedthe use of I-131 in nuclear medicine using UM's Ford Nuclear Reactor

(1950s and 1960s) Developed the first university-based programs in rocketry and guided missile technology for the Air Force

(1960s) Became a major astronaut training center

(1960s) The Apollo 15 mission had an all Michigan crew (and a car) on the moon

(1950s) Developed first degree program in computer engineering

(1953) Jonas Salk, research associate and fellow in the U-M School of Public Health from 1940-44, developed in 1953 the polio vaccine.

(1954) Donald Glaser, developed in 1954 the world's first liquid bubble chamber to study high-energy subatomic particles and won the Nobel Prize in physics for his invention in 1960

(1955) Clinical trials for Salk vaccine for polio (Thomas Francis)

(1957) Chihiro Kikuchi, professor of nuclear engineering, developed in 1957 the ruby maser, a device for amplifying electrical impulses by stimulated emission of radiation

(1957) Alumnus John Sheehan, pioneered in 1957 development of synthetic penicillin, the life-saving antibiotic discovered in 1928 and developed ampicillin, a semi-synthetic penicillin taken orally.

(1958) Faculty member C. Wilbur Peters and Lawrence E. Curtis developed in 1958 a fiberoptic technique leading to medical endoscopy technology.

(1959) First program in engineering meteorology and later atmospheric science

(1960) First program in computer and communications science

(1964) Alumnus Jerome Horwitz, an organic chemist at Michigan Cancer Foundation, synthesized in 1964 the drug AZT, which is used to fight AIDS.

(1960s, 1980s) Peace Corps and later Americorps announced at UM.

(1960s) Developed time-sharing computing (MTS with IBM).

(1960) First courses in thermonuclear fusion for AEC

(1962s) Developed laser holography (Emmett Leith and Juris Urpatnieks).

(1962) Center for Research on Learning and Teaching is first research center on university teaching.

(1963) First university research institute on hearing and deafness (Kresge Hearing Research Institute)

(1964) Center for Education of Women (CEW), the first center focused on enabling the continuing education of women (Jean Campbell and Louise Cain)

(1960s-1970s) Willow Run Labs development of satellite remote sensing.

(1968) Alumnus Marshall Nirenberg shared the 1968 Nobel Prize in medicine and physiology for cracking the genetic code

(1968) John G. Wagner, professor of pharmacy, began to develop pharmacokinetics, a field that uses mathematical models to study the body's metabolism of drugs, and to determine safe dosage levels

(1969) Richard C. Schneider, professor of neurosurgery, co-patented a football helmet with an inflatable inner lining that is designed to reduce head injuries

(1970s) MERIT Computer Network (Eric Aupperle)

(1970s) Discovery that CFCs cause Ozone Hole (Ralph Cicerone)

(1972) Founding of the nation's first Anxiety Disorders Program (George Curtis)

(1976) Alumnus Samuel C. C. Ting shared the 1976 Nobel Prize in physics for co-discovering a subatomic structure called the J particle.

(1982) Discovery that Venus seas were lost to greenhouse gases (Thomas Donahue).

(1980s) Computer-Aided Engineering Network (Richard Phillips, Daniel Atkins, Randy Frank)

(1985) Key Study and Senate testimony on health implications of tobacco (Kenneth Warner); Tobacco Research Network established in 1999.

(1985) Alumnus Richard Smalley, along with two other scientists, won 1996 Nobel Prize in chemistry for the 1985 discovery of a form of the carbon element in the faceted shape of a soccer ball called fullerene.

(1986) Alumnus Stanley Cohen was co-winner of the 1986 Nobel Prize in medicine for discovering growth factors (proteins regulating cell growth) in human and animal tissue.

(1987) Development of high-power chirped-pulsed lasers (Gerard Mourou, winner of the Nobel Prize)

(1987) Douglas Richstone, professor of astronomy, discovered in 1987 evidence for massive black holes in the Andromeda Galaxy and its satellite galaxy M32

(1988) Art Rich and James Van House develop positron microscope.

(1980s) NSFnet and the Internet (with IBM and MCI) (Doug Van Houweling, Eric Aupperle)

(1980s) Development of Photoshop and software for digital photography (Tom and John Knoll)

(1990) Donabedian Paradigm statistical model for ranking hospitals and health care facilities (Avedis Donabedian)

(1990s) Francis Collins identifies gene for cystic fibrosis and neurofibromatisis.

(1990s) Developed JSTOR project for the Mellon Foundation (Randy Frank, Daniel Atkins)

(1990s) NSF Digital Library Project

(1990s) First School of Information (and informatics program) (Dan Atkins)

(1996) Created the Media Union (aka Duderstadt Center) to explore paradigms for the future of higher education.

(1997) Developed technology for operating research nuclear reators on low-enrichment (non-weapons-grade) uranium to secure nonproliferation (John Lee)

(1998) Mark Burns headed 1998 multidisciplinary team that created miniature “laboratory on a chip” for the analysis of DNA samples.

(1999) Alumnis Tony Fadell creates the iPod (and subsequent mobile devices such as the iPhone).

(2003) FDA approves FluMist nasal flu vaccine developed at the School of Public Health (Hunein “John” Maassab)

(2000s) Alumnus Larry Page creates Google, the nation’s leading search engine

(2004) UM Libraries as leader in Google Book project

(2006) Created first University National Depression Center (John Greden).

(2008) Created and managed the HathiTrust (world’s largest digital library).

(2010s) Involvement of SPH on Genome Wide Association Studies identifying key (druggable) targets for widespread and orphan disease (Goncalo Abecasis and Mike Boehnke).

(2010s) SPH and UM Cancer work on understanding responses to chemotherapies.

(2010s) Michigan became a leader in online learning and research through its efforts in Academic Innovation, including MOOCs, micromasters programs, teach outs, and learning collaboratories.

(2010 to 2020) Yet to be added...

Chapter 2

The Hypothesis

It is hard for those of us who have spent much of our lives as academics to look at the university, with its traditions and obvious social value, and accept the possibility that it soon might change in dramatic ways. Although the university has existed as a social institution for almost a millennium, with each historical epoch it has been transformed in very profound ways.

The scholasticism of early medieval universities, first appearing in Bologna and Paris, slowly gave way to the humanism of the Renaissance. The graduate universities appearing in early 19th century Germany (von Humboldt's University of Berlin) were animated by the freedom of the Enlightenment and the rigor of the scientific method. The Industrial Revolution in 19th America stimulated the commitment to education of the working class and the public engagement of the land-grant universities. The impact of campus research on national security during WWII and the ensuing Cold War created the paradigm of the contemporary research university during the late 20th century.

Although the impact of these changes have been assimilated and now seem natural, at the time they involved a profound reassessment of the mission and structure of the university as an institution. But the pace of change in our world is accelerating, with the impact of rapidly evolving technology, changing demographics, and the impact of humankind on our planet. These will pose great challenges to our universities in the next few decades.

As noted in the first chapter, in addition to its long history of leadership in education and scholarship, from time to time the University of the Michigan has made major contributions that have changed our world in fundamental ways. In this book we will focus on its role over the past half century in developing three technologies that have had an impact similar in character to these earlier periods of change in world history:

The Universitas (enabling new "unions" of people)

Of course, the resources for communicating and building "universitas" or unions such as guilds, cities, and, of course, universities themselves have steadily evolved since Medieval times, through transportation (roads, ships, railroads, automobiles, planes,…) and communication (…sign language, pony express, telegraphs, telephones, television,...). But the unprecedented pace of evolution of digital technology, increasing in power roughly 100 to 1,000 fold a decade, has created entirely new forms of communication, from e-mail to video transmission to immersive environments (virtual and augmented reality). But the most profound impact has been through the Internet and supporting software such as the Worldwide Web, which has made this form of communication truly available on a global level.

The Renaissance (providing access to knowledge to meet the needs of society…including its creativity)

Although the printing press enabled the distribution of knowledge through book and libraries, these objects had limited access (constrained by cost, location, languages, etc.) But by the early 1990s, the digitization of written material became both affordable and available (through the evolution of intellectual property laws). The Mellon Foundation took an important step through the support of the JSTOR project enabling the University of Michigan to digitize and provide Internet access to large numbers of history and economics books. The implications of such projects to create "digital libraries" available to millions of scholars stimulated the University of Michigan to broaden its School of Library Science to include information technology in its curriculum (becoming first a School of Information and Library Science and then later the nation's first School of Information focusing on the production of "informationists" capable of guiding searches in cyberspace rather simply librarians managing books. Working with existing IT companies such as Google (with the massive Google Books digitization project), universities (with the even larger HathiTrust digital library consortium), and net-denizens such as Wikipedia , the University helped build the tools that enable millions of people to interact, create, and modify sources of information on the Internet. This collection of digital knowledge resources and applications would acquire the name "cyberinfrastructure".

The Enlightenment, providing not only access to the existing knowledge of the world but as well the learning necessary to use it to create new knowledge.

Any vision proposed for the University's future must consider the extraordinary changes and uncertainties of a future driven by exponentially evolving information and communications technology. The great connectivity provided by the Internet already links together the majority of the world's population. To this, one can add the emerging capacity to capture and distribute the accumulated knowledge of our civilization in digital form and provide opportunities for learning through new technologies such as augmented and artificial reality, collaboratories, and intelligent tutors. Universities will be key, but they must invest in new resources combining not only the traditional learning goals of the curriculum but also the creative spirit of the arts and sciences. They must both serve and adapt to an emerging global society no longer constrained by space, time, monopoly, or archaic laws and instead even more dependent upon the elements of a new Enlightenment based upon reason, science, humanism, and progress.

The University of Michigan has had an important role in each of these major evolutionary stages of the digital age. A brief summary of Michigan's contributions within the context of world history will help to understand its unique role in changing our world.

The *Universitas* or Age of Unions

The Middle Ages from 5th Century to 14th Century are sometimes referred to as the "Dark Ages". It certainly was "postclassical" after the civilizations of Greece and Rome. Yet it was far from "dark", since beginning in the 12th Century new social structures began to appear, first triggered by the role of the church, not so much because of its religion, but because of its creation of organizations such as monks and the communities of workers necessary to construct great cathedrals,. Latin, served as the common language to enable the communication necessary to bring people together. Events such as the Crusades exposed Western Europe to the Islamic cultures of the East, and by the 13th Century, the guilds and cities necessary for trade and commerce were formed. (See Appendix for an interesting portrayal of world history...courtesy of Walt Disney and Dame Judi Dench!)

By the 14th century, schools and universities appeared to train citizens for the evolving civilization. Great teachers such as Peter Abelard of Paris and Irnerius of Bologna were attracting scholars from across Europe to form learning unions consisting of masters and scholars, or in Latin, *Universitas Magistrorum et Scholarium*, the foundation of today's universities.

Since all medieval universities not only taught in Latin, but furthermore accepted the same degree structure, it was quite easy for students to freely choose their university, discipline, and teachers without concern to nationality. The study of many students acquired a nomadic character, moving from place to place, university to university, teacher to teacher, until completing their studies. Students from similar origins and languages would frequently live and study together in associations called *nations*. This migratory character, enabled by instruction in a common language, Latin, and similar degree requirements would last until the 17th Century when more differentiation among universities would appear. (De Ridder-Symoens, in Reugg, 1992)

Universities began to proliferate throughout Europe

Students were attracted to learn from great scholars such as Irnerius of Bologna and Abelard of Paris.

Master and scholars

as groups of faculty and students left their original universities seeking new teachers or learning disciplines. Bologna served as the model for the development of the medieval university in Italy, Spain, Portugal, and the rest of southern Europe. North of the Alps, the University of Paris proved most influential. Within a short time similar universities were established in Toulouse (1220) and Montpellier (1229). By 1500 France had 16 provincial universities, and the German lands had 17 universities). In contrast, England remained with only two universities, Oxford and Cambridge, but between them, they had 22 colleges. With the sole exception of Oxford and Cambridge, all of the European universities were situated in medieval cities. (Clark, 2006)

Fast Forward to the 21st Century:

Of course, the resources for communicating and building "universitas" or unions have steadily evolved since Medieval times, through transportation (roads, ships, railroads, automobiles, planes,…) and communication (…pony express, telegraphs, telephones, television,...).

Today, the University of Michigan is clearly playing a leadership role in achieving just such a vision. Its efforts during the 1980s (together with IBM and MCI) to build and manage the backbone of the Internet, its role in creating Internet2, and most recently the early effort to create a "national learning, research, and innovation network" linking together the nation's research universities, national laboratories, federal agencies, and industry with advanced cyberinfrastructure provide strong evidence of the leadership role it plays in linking together people and institutions around the world.

But the unpredented pace of evolution of digital technology, increasing in power 100 to 1,000 fold a decade, has created entirely new forms of communication, from e-mail to social media to immersive environments (virtual and augmented reality). Perhaps the most profound impact has been through the Internet and supporting software such as the Worldwide Web, which has made this form of communication truly available on a global level. New "universitas" structures have appeared such as Facebook (with the objective of connecting all of the world's people), Google (with the mission of collecting all the knowledge in the world and making it available for all the worlds people), and Amazon (using the Internet to create a "store" providing any commodity to any of the world's people).

The Renaissance

While the medieval university provided the model for higher education first in Europe, then in North America, and eventually throughout the world, it was largely a bystander to the great intellectual movements of the 15th and 16th century: the Renaissance and the Reformation. (Lohmann, 2002) The medieval universities held fast to the traditions of *scholasticism*, both in philosophy and pedagogy, even as the intellectual movement of the Renaissance


Disruptive technology: the printing press

placed importance on *humanism*, the study of human nature and worldly topics rather than religious ones. Renaissance humanists believed that the liberal arts (art, music, grammar, rhetoric, oratory, history, poetry, using classical texts, and the studies of all of the above) should be practiced by all levels of "richness". They stressed the importance of self, human worth and individual dignity rather than religious dogma. (Verger, 1992)

Emerging from 14th century Florence, the humanist movement was stimulated by the discovery by scholars of many ancient texts in their original Latin and Greek. It represented a sharp departure from the scholasticism of the Middle Ages, and resulted in an age in which poetry and oratory, painting and sculpture, architecture and music became popular. As the printing press replaced medieval manuscripts with printed books, humanism moved from being an Italian phenomenon into being a European movement. Scholasticism, the Inquisition, superstition, and feudal society were decisively changed through the revolutions of the 17th and 18th centuries. (Haskins, 1957)

Fast Forward to the 21st Century

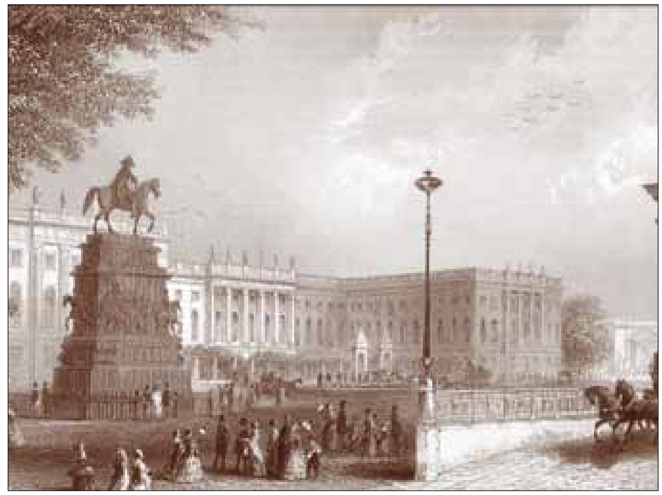
Although the printing press enabled the distribution of knowledge through book and libraries, these objects had limited access (constrained by cost, location, languages, etc.) But by the early 1990s, the massive digitization of written material became both affordable and available (through the evolution of intellectual property laws).

The University of Michigan has played a leadership role in redefining the nature of the "library" for a digitally connected world, first with the NSF digital library project in the 1990s–a consortium of universities that stimulated the development of the Page Rank search algorithm and the creation of Google, and helping to build the JSTOR project, the first major effort to digitize a massive collection of scholarly publications in disciplines such as economics and history. Michigan served as the lead partner in the Google Books project, to provide search access to the printed knowledge of the world, and today leads the HathiTrust, a collection of 80 leading libraries with the furher goal of providing full-text access to large inventories of scholarly materials. The implications of such projects to create "digital libraries" available to millions of scholars stimulated the University of Michigan to broaden its School of Library Science to include information technology in its curriculum (becoming first a School of Information and Library Science and then a School of Information focusing on the production of "informationists" capable of guiding searches in cyberspace rather than simply librarians managing books. Again both existing IT companies such as Google (with the massive Google Books digitization project), universities (with the even larger HathiTrust digital library consortium), and Wikipedia (enabling millions of people to interact to create and modify sources of information on the Internet. This collection of digital knowledge resources and applications would acquire the name "cyberinfrastructure).

The Enlightenment (1700 – 1800)

The intellectual movement of the Enlightenment, emerging in the early 18th century, had great impact on universities as scholars as not only knowledge but learning begin to take on new forms such as the sciences to enable it to not only spread about the globe but also trigger major social change. Although the Enlightenment idealized the concepts of democracy and republic from Greek and Roman civilizations, scholars such as John Locke interpreted these as implying that citizens held certain natural rights such as life, liberty, and property, and that governments derived their

Wilhelm von Humboldt



The University of Berlin
(renamed Humboldt University in 1949)

existence from the consent of the governed and their duty to protect these rights. If a government did not protect these individual rights, then the people had the right to overthrow it–a message that was soon heard both in the New World (the American Revolution) and in 18th century France. (Ruegg II, 1996).

The Enlightenment created a strong movement for a general improvement in human life, which began in England and passed through France, providing the model for thought throughout the Continent and leading to revolution against established authority. In 1803 the French Revolution abolished the older academic system and closed all colleges and universities. They were replaced by new schools and technical academies, écoles and polytechnics, including at the highest level the "Grand **É**coles", which produced the leaders of government and science in the new French republic. In 1810 Napoleon went further by creating his *Université Impériale de France* as an administrative structure to oversee all higher learning in France and its conquests. (Recall that the early design of the University of Michigan was based on this French model of a universal learning institution). (Turner, 1988)

Napoleon attempted to apply the *Universitié Impériale* system to his conquests across Europe. After he defeated the Prussians in 1806, he closed the University of Halle. Yet this disappearance of Prussia's leading university triggered the emergence of a new institution, the University of Berlin, which would adopt a new paradigm that would eventually dominate Europe: the research university. This approach, usually associated with Wilhelm von Humboldt, Prussian minister of education, was built on the belief that the function of the university should be broadened beyond learning to include scholarship, the creation of new knowledge itself. (Lohmann, 2003)

Wilhelm von Humboldt argued that, unlike the new French **É**coles, the envisaged institution in Berlin must include all the traditional disciplines. He rejected both the medieval structure of the university and the French model of professional colleges, arguing instead for the importance of not simply conveying knowledge but actually generating research as a responsibility of the faculty, thereby laying the foundations for the modern research university. von Humboldt argued that one must always treat academic knowledge as something being sought, as a task never perfected. It was something organic and reaching into the depths. Furthermore, both the freedom to learn, *Lernfreiheit*, and the freedom to teach, *Lehnfreiheit*, would become the foundation of academic freedom characterizing the new universities emerging in the 19th and 20th centuries.

With the arrival of its first president, Henry Tappan, familiar with the Enlightenment universities emerging in Europe, Michigan would become one of the young nation's first true universities, combining both learning and scholarship, much in the model of von Humboldt

Fast Forward to the 21st Century

As participant in the OpenCourseWare and MOOC movements to provide global access to learning resources, the University has firmly established its leadership role in providing both knowledge and learning on an unprecedented global scale. Its leadership in promoting open access to research data and intellectual property through efforts such as the Creative Commons has potential for redefining the public university as a "knowledge commons" serving the world.

Yet any vision proposed for the University's third century must consider the extraordinary changes and uncertainties of a future driven by exponentially evolving information and communications technology. The extraordinary connectivity provided by the Internet already links together the majority of the world's population. To this, one can add the emerging capacity to capture and distribute the accumulated knowledge of our civilization in digital form and provide opportunities for learning through new paradigms such as digital libraries, cyberinfrastructure, and collaboratories. Yet such rapidly evolving technology also poses certain challenges, such as the propagation of "false truth" through social media such as Twitter and the role that artificial intelligence and deep learning will play in challenging human intellect and control.

This suggests the possible emergence of a new global society no longer constrained by space, time, monopoly, or archaic laws and instead even more dependent upon the generation of new knowledge and the education of world citizens. In such an era of rapid change, it has become the responsibility of democratic societies to provide their citizens with the learning opportunities they need throughout their lives, at costs they can afford, as a right rather than a privilege.

What the nation (and the world) needs today is a 21st century version of the Enlightenment movement of the 17th and 18th century that swept aside the divine authority of kings by educating and empowering the public, stimulating revolution, and creating the liberal democracies that now characterize most developed nations. Our nation and our world needs once again the "illumination" provided by distributing "the light of learning and knowledge" to counter the ignorance (e.g., today's "denier" culture) and address the challenges of our times.

More specifically, the goals of the Enlightenment were to provide for a rational distribution of freedom, universal access to knowledge, and the formation of learning communities. Rational and critical thought was regarded as central to freedom and democracy. Knowledge and learning were regarded as public goods, to be made available through communities such as salons, seminars, and academies. These dreams of the universal and the collective, *Liberte, Egalite, and Fraternite* for the French Revolution–or perhaps better articulated by Jefferson's opening words from our Declaration of Independence: "We hold these truths to be self-evident, that all men are created equal, that they are endowed by their Creator with certain unalienable Rights, that among these are Life, Liberty and the pursuit of Happiness."–remain as important today as they were three centuries ago.

Today, the educational institution most capable of launching a new "age of Enlightenment" is the "university", with its dual missions of creating "unions" of scholars and learners and providing "universal" access to knowledge. In a sense, the word "university" itself conveys the elements of this vision: both the sense of a "union" or community of learners (i.e., universitas *magistrorum et scholarium*) and the "universality" or totality of knowledge and learning as the key to social well-being in an age of knowledge. Furthermore, since these have been regarded as public goods, one might even suggest that the public universities have a particular responsibility in providing these.

But while the Enlightenment of the 18th century was concerned with "celebrating the luminosity of knowledge shining through the written word", today knowledge comes in many forms–words, images, immersive environments, "sim-stim". And learning communities are no longer constrained by space and time but rather propagated instantaneously by rapidly evolving technologies (e.g., cyberinfrastrucure) and practices (e.g., open source, collaboratories). The ancient vision of the Library of Alexandria to collect all of the books of the world in one place is rapidly becoming true–except the "place" has now become a cloud in cyberspace. Learning communities are evolving into knowledge generating communities–collaboratories, wikis, crowd sourcing, and hive cultures that span the globe.

William Germano suggests yet another argument for such a theme as the possible next stage in speculating about the evolution of the "book", from the invention of writing to the codex to the printed volume to the digital revolution. As he explains:

> "Right now we are walking through two great dreams that are shaping the future of scholarship, even the very idea of scholarship and the role "the book" should play within it. Great Dream No. 1 is universal access to knowledge. This dream means many things to many people, but for knowledge workers it means that scholarly books and journals can, and therefore should, be made available to all users. New technologies make that possible for the first time in human history, and as the argument goes, the existence of such possibilities obligates us to use them. Great Dream No. 2 is the ideal of knowledge building as a self-correcting, collective exercise. Twenty years ago, nobody had Wikipedia, but when it arrived it took over the hearts and laptops for undergraduates and then of everyone else in the education business. Professional academic life would be poorer, or at least much slower, without it. The central premise of Wikipedia isn't speed but infinite self-correction, perpetually fine-tuning what we know. In our second dream, we expand our aggregated knowledge quantitatively and qualitatively". (Germano, 2010)

In a sense, then, the concept of a 21st century analog to the Enlightenment combines several themes that we suggested earlier might characterize the university of the future:

The emergence of a *Universitas Magistrorum et Scholarium* in cyberspace.

The power of network architectures in distributing knowledge and learning

The increasing access to knowledge and learning resources through the massive digitization and access to printed materials and other sources of information

The perspective of learning organizations as ecologies that evolve and mutate into new forms

Developing a vision for a hazy future

The university as the prototype of an emergent global civilization

Our proposition is that the Enlightenment theme is a particularly compelling and appropriate goal for the University of Michigan's third century. as it explores the future of academic innovation. After all, our future will continue to be one in which freedom and prosperity depend upon widespread distribution of "the light of learning and knowledge", and hence this should become a key component of our extended public purpose.

A Vision for the University of Michigan's Future

We have suggested roles that the University of Michigan has played in achieving creating both technologies and the visions for the use of these new tools:

A vision capable of creating new "universitas" or "unions" of people, connected together by the ubiquitous technology of the Internet.

A contemporary vision of a Renaissance, achieved by new technologies such as digital libraries and cyberinfrastructure, as the University aligns itself to better engage with a world dependent upon learning, knowledge, creativity, and innovation by spanning the broad range of learning from simply "to know", "to do", "to create" and "to become; and

A longer term vision of the Enlightenment as the University commits itself to expand its public purpose to provide "the light of learning and knowledge" to the world in the new forms of academic innovation, enabled by rapidly evolving information and communications technologies such as artificial intelligence and deep learning.

Hence, it is appropriate (and provocative) to suggest that the University is well-positioned to participate in a contemporary version of the Enlightenment, spreading knowledge and learning throughout the world. We suggest that this might become the primary mission of the University for its Third Century!

Although bold, we believe these visions to be consistent both with the University's heritage and the challenges and opportunities it will face as it begins its third century. As one of the nation's first experiments in public higher education, its first attempt to build a true "university" in the European sense, with a public purpose of providing "an uncommon education for the common man", and "creating a community of scholars across the full range of disciplines", such a vision aligns well with the University's history and heritage. But, these visions also seem consistent with both the recent and ongoing activities of the university and its culture of innovation and risk-taking to not only address the challenges of our times but to create the future.

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Chapter 3

The Precursors

The University of Michigan has long provided national leadership for higher education in the application of technology to teaching and research. Perhaps no area illustrates this more vividly than its leadership in the development and application of computers and, more broadly, information and communications technologies. Michigan has not only easily adapted to each transformation in these technologies, but it has led in the transitions of early mainframe computers to timesharing to networked computer workstations to the Internet and today's global networks of data centers, search engines, big data, and open knowledge resources.

Early Activities

During the post WWII era, Michigan was among the earliest universities to explore the use of the digital computers. Michigan faculty member Arthur Burkes participated in the development of the first electronic computer, ENIAC (a portion of which is displayed in the University's Beyster Building for Computer Science and Engineering). The University's Willow Run Laboratories installed an early computer, MIDAC (Michigan Digital Automatic Computer) in 1952, but the use of computers in teaching and research really began with a series of IBM mainframe computers, the IBM 650, 704, and 7040, installed on campus during the 1950s and 1960s. University faculty members including Bernard Galler, Donald Katz, James Wilkes, and Brice Carnahan led the efforts to apply these computers to both teaching and research, developing the first courses in computer programing and later new academic degree programs such as Computer and Communications Sciences (in LS&A) and Computer Science and Engineering (in Engineering).

The University also led in the development of the software for these computers, first developing the MAD (Michigan Algorithm Decoder) programming language in 1960 and then one of the first time-sharing operating systems, MTS (Michigan Terminal System), for building a University-wide network using the IBM 360/67 mainframe computer in 1966. The MTS system, operated by the University Computer Center directed by Robert Bartels, not only became the workhorse of the University's teaching and research activities, but soon was adopted by many other universities. (Wilkes, 2014)

The MERIT Computer Network

The University's leadership in networking technology soon led to a statewide computer network, MERIT, (Michigan Education Research Information Triad), linking together the major universities in Michigan (initially UM, MSU, and WSU). Led by Eric Aupperle, the MERIT network, supported by a combination of state support and NSF grants, was activated in 1971 and evolved to become not only a state-wide network but provided standards-based links to computing systems across the nation and around the world, establishing much of the technology that would become key to NSFnet and the Internet in the 1980s.

Eric Aupperle, MERIT's Director and President from 1974 until 2001, recalls that this was stimulated by Michigan Governor George Romney in 1964 with a vision of shared distance education. Michigan researcher Karl Zinn had the idea of developing a computer network to allow the universities to link their computer networks.

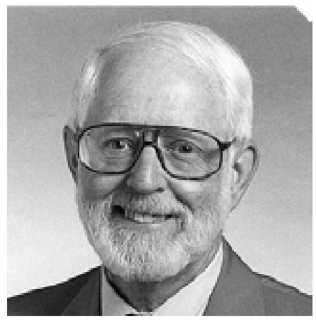
The universities through MERIT approached the state of Michigan's government and sought funding.

Donald Katz

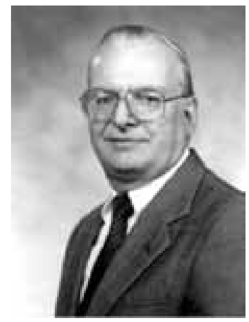
Bernie Galler

Arthur Burkes

James Wilkes



Brice Carnahan



Eric Aupperle

And then in two successive legislative years 1967 and 1968, receiving $200,000 each year to initiate Merit. In 1969 Merit was able to obtain a grant of $400,000 to match the state appropriations.

The project was predicated on the use of IBM's first time-sharing computer, the 360-67, and software, TSS/360. The Merit supported many important developments, including the early timesharing system at the University, the Michigan Terminal System (MTS). As we will describe in the next chapter, it also included one project that proved particularly important to the later development and implementation of NSFNET, the Data Concentrator. It was Digital Equipment Corporation (DEC) PDP-8 minicomputer with custom hardware and software that enabled the IBM computer to be connected to a variety of interactive computer terminals. (Wilkes)

The only networking effort comparable to MERIT's underway at the time was the Department of Defense's ARPANET project at Bolt, Beranek and Newman (BB&N). Just as it was focused on networking a number of specialized research computers supported by ARPA grants, MERIT had committed to link the mainframe computers at its member institutions together so researchers at any of the universities could utilize the combination of computing technology best suited to their work. As the MERIT NSF proposal stated, "When the computing facilities of a single university are joined by a common network to the computing facilities of other universities, its computing resources will then be greater than the sum of the resources of all the universities in the network…. Thus, to any single user at any point of entry to the network, the whole system appears more powerful and responsive to his needs than the collection of individual systems could be if addressed on an individual basis."

MERIT eventually decided to contract with a local systems house, the Applied Dynamics Division of Reliance Electric, to fabricate the required hardware interfaces for the DEC PDP-11 minicomputer. Between 1969 and 1971 the Applied Dynamics and MERIT staff collaborated in the design and implementation of the Communications Computers along with the Communication Computers' network operating system (CCOS) and installed a Communication Computer at each member university. The first connections

From sliderules and calculators to Eniac to early IBM mainframes and finally to the Michigan Terminal System

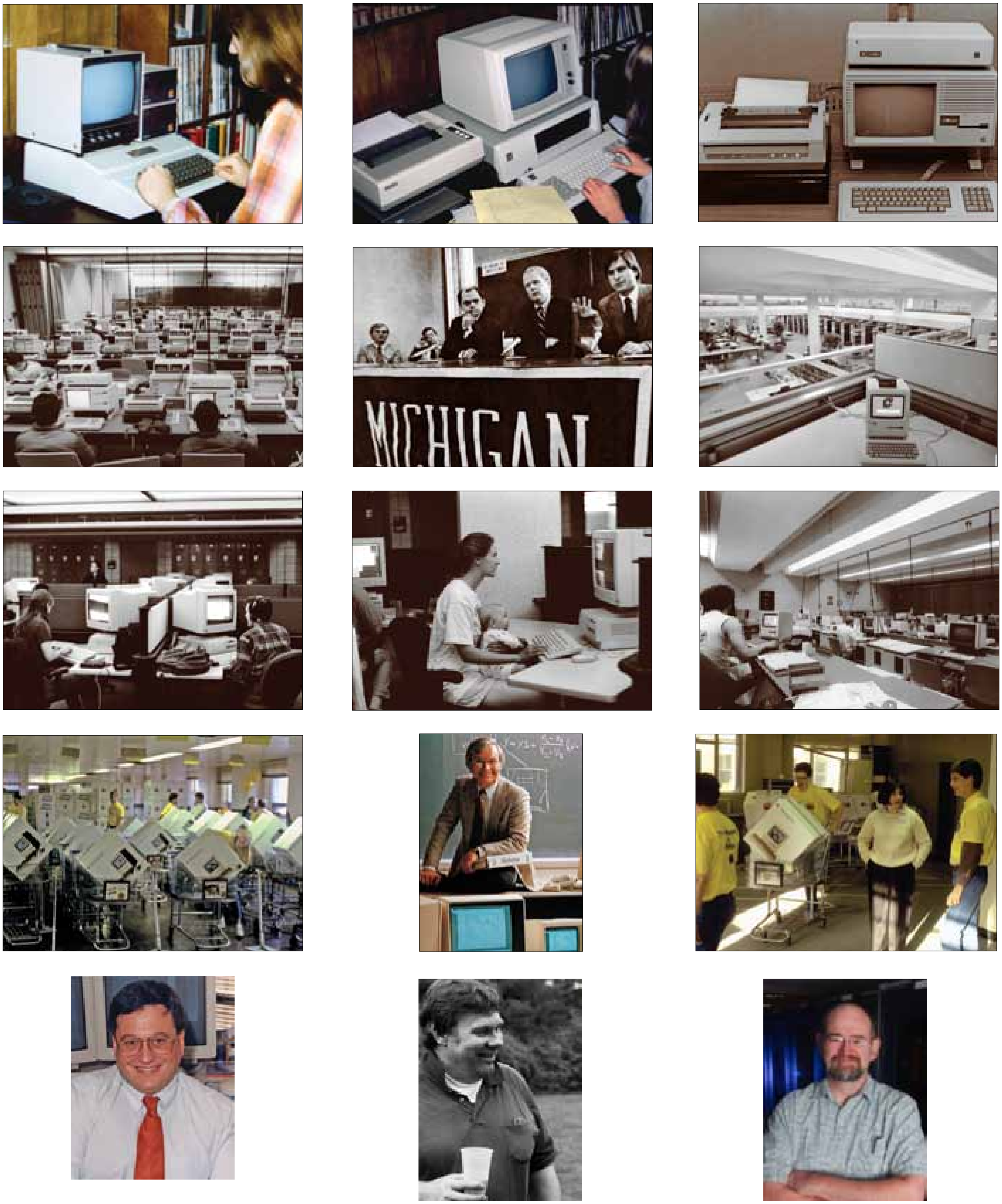
between the University of Michigan's and Wayne State University's computers became active on December 14, 1971. Michigan State's Control Data computer was brought on line and the Merit network was formally dedicated in May, 1973. MERIT has continued to provide advanced networking capabilities to its members ever since, making it one of the longest serving network service providers.

Over the next 15 years it evolved into a regional network, not only providing connectivity but developing software tools such as e-mail, teleconferencing, and collaboration environments. As we will see in the next chapter, MERIT was well positioned to respond with partners IBM and MCI to an RFP from NSF to build a broad scientific network, NSFnet, that would link together the NSF supercomputers centers with a national network for research and education. Soon other networks such as ARPAnet, Bitnet, and CSnet were swept into this "internetwork", and of course, this became the backfbone of the Internet that has so transformed our world today.

Of course, in the early days few had any idea that a small regional network would grow into an effort that would transform the world. Who could have anticipated the emergence of killer applications such as the World Wide Web or the browser that would trigger an avalanche of users (increasing at a rate of 10% per month during the 1990s). (Van Houweling)

MTS: the Michigan Terminal System

The University's time-sharing system, the Michigan Terminal System (MTS), continued to evolve through the 1970s and 1980s, moving from IBM mainframes to more powerful Amdahl computers, and gaining a reputation as one of the nation's leading computer



From Apple II to IBM PCs to Apple Lisas to the Computer Aided Engineering Network
(led by Dick Phillips, Randy Frank, Don Geister, and Paul Killey)

environments for teaching and research. But the very success of the MTS system, its centralized structure, and its home-grown character, rapidly lost ground to the new generation of minicomputers such as Data Equipment Corporation's VAX minicomputer systems for science and engineering applications. By the end of the 1970s, most engineering and science departments at top research universities had acquired their own VAX systems. Yet, Michigan remained not only moored to the increasingly aging mainframe-based MTS system, but also to centrally administrated computer policies that prevented academic programs from breaking away and acquiring more advanced computing environments. In fact, every purchase of a computer had to be approved by a central committee at the University.

CAEN: The Computer Aided Engineering Network

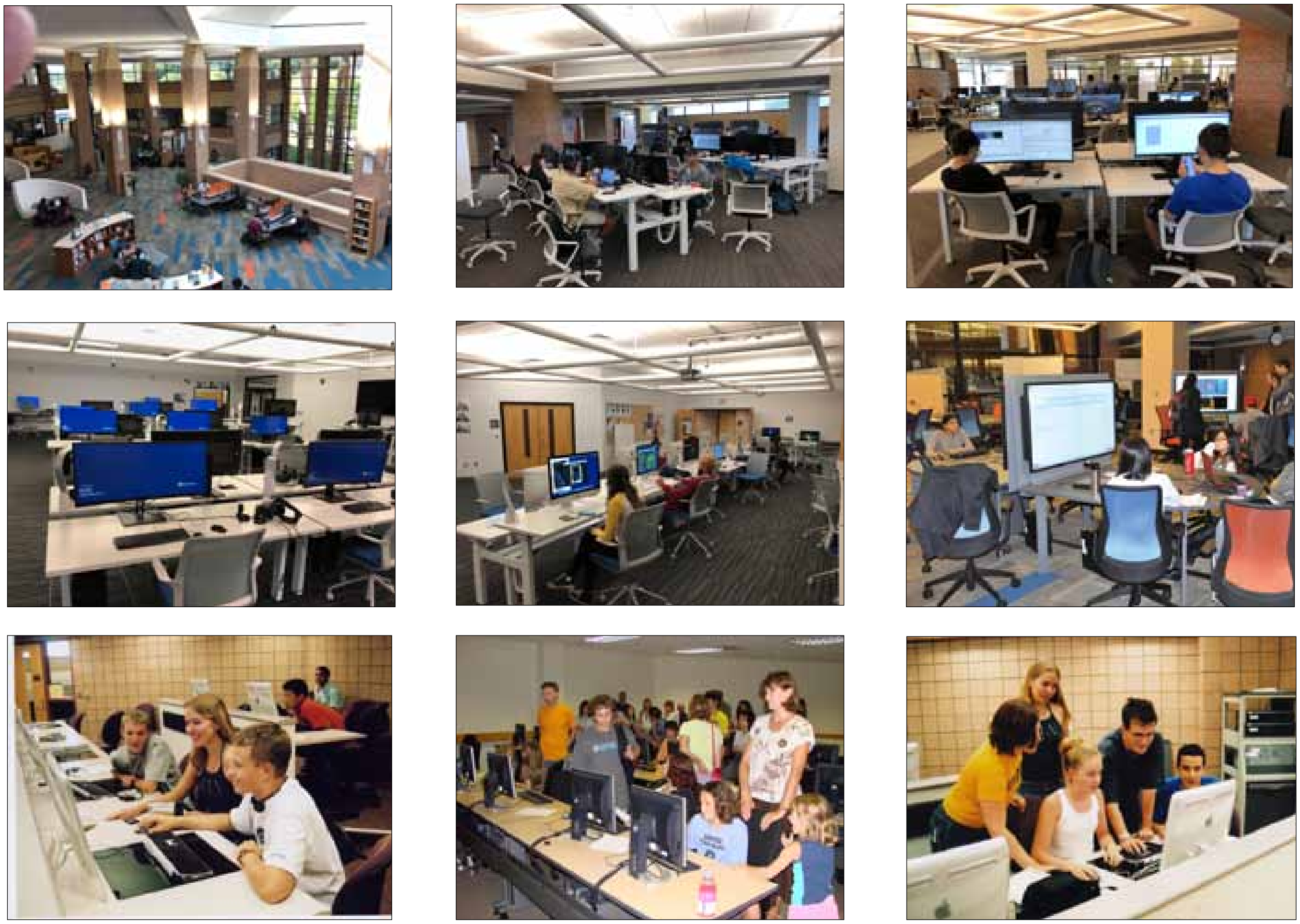
The constraints to the MTS system became of increasing concern to the College of Engineering, whose faculty members were experienced in using both minicomputers (e.g., DEC's VAX computers) and the emerging microcomputers such as the TRS-80 and the Apple II computer. Dick Phillips and Bill Powers of the Department Aerospace Engineering stimulated interest in the use of the first microcomputers such as the TRS-80 and Apple II for instructional purposes. In fact, this led to one of the very first introductory computer courses on these systems in the late 1970s.

From these experiences, it was clear that the College of Engineering simply had to break away from the University's MTS system and build its own computing environment, more suited to its needs. The College was convinced that the digital computer would rapidly evolve from simply a tool for scientific computation and information processing into an information technology infrastructure absolutely essential to all of our activities, from research to instruction to administration. Hence, to build a leading engineering college, it would have to become a leader in information technology. This view was shared by many members of the College.

Dan Atkins assumed the leadership for this effort, assisted by Dick Phillips, Lynn Conway, and other members of the faculty. They set a rather ambitious goal: To build the most sophisticated information technology environment of any engineering college in the nation, an environment that would continually push the limits of what could be delivered in terms of power, ease of use, and reliability to our students, faculty, and staff. The system was called CAEN, the Computer Aided Engineering Network, a name reflecting its functional architecture as a sophisticated information technology network integrating the College's instruction, research, and administrative activities together with both oncampus users (students, faculty, staff) and offcampus participants (industry, government, alumni). More technically, CAEN was envisioned as a distributed intelligence, hierarchical computing system linking personal computer workstations, superminicomputers, mainframe computers, function-specific machines (CAD/CAM, simulation) and gateway machines to national networks and facilities such as supercomputer centers. The network was designed to support not only general scientific computing, but computer-aided instruction, administrative services, and access to technical and bibliographic databases.

The College first had to fight a battle with the University administration to allow it to break away from the MTS system. Fortunately it was easy to convince President Harold Shapiro and Billy Frye that they needed to encourage more diversity in computing, and in particular, allow some units to move far out on the curve of advanced computing as pathfinders for the rest of the University. Engineering and Business Administration were given the go-ahead to build their own environments (which would eventually lead to the disappearance of MTS, although it would take almost a decade).

The College of Engineering moved ahead with the transition from a mainframe time-sharing system to microcomputer/workstation networks by first providing every member of the faculty with a personal computer (a choice of either an IBM PC or an Apple II computer). Actually, there was an interesting wrinkle to this offer, since the College asked each faculty member also to take a second computer home, the rationale being the likelihood that their families would serve as an additional stimulus to become "computer literate". Interestingly enough, this program had unexpected impact when the teenage sons of one faculty member became so adept at programming the Apple II computer brought home by their father, that



Computing clusters at the University

they managed to develop commercially successful software for editing photographic images. You may have heard of the software…Adobe's Photoshop! (Tom Knoll and John Knoll together developed this software that revolutionized the field of digital photography. Tom Knoll became the technology leader at Adobe, and John Knoll became a leader in the field of computer animation at George Lucas's Industrial Light and Magic and today is leader of CGI at the Walt Disney Company.)

The College next began to acquire several networked clusters of state-of-the-art computer workstations for research (Apollo, Sun, HP, Apple, Silicon Graphics). It faced a very major challenge in providing adequate computing resources for its students, since the College's large enrollments (6,000) would require a massive investment. To address this, the College persuaded the University to allow it to charge students a special $100 per term computer user fee to help support their computing environment. This generated $1.5 million each year that it then could use to buy (or even debt-finance) computer equipment. To provide a vivid demonstration of just what the students were getting for their fees, two large lecture rooms on the first floor of the Chrysler Center were converted into a gigantic computer cluster, equipped with over 100 of the new Apple Lisa workstations. This was quite a sight—probably the largest collection of Apple Lisas that ever existed—and it really impressed the students. The College adopted the philosophy that these were the students' computers, without any constraints on how they could use them. Similar computer clusters were later distributed across the University.

A contrast...between the UM computing clusters...

...and a printing press for the School of Art and Design

Extending Micro Computers to the University Level

In 1984 Doug Van Houweling was able to extend the concept of a computer user fee to the rest of the University to create computer clusters throughout the UM campus, providing powerful resources for all of the students, faculty, and programs of the University.

The second element of the plan for students involved developing a mechanism to help them purchase their own personal computers, since Van Houweling realized that the University would never have sufficient assets to equip all enrolled students. Van Houweling explored the possibility of negotiating very deep discounts (60% or more off list price) with key vendors such as Apple and IBM. After considerable effort, he finally managed to convince President Shapiro that the leading universities would be achieving massive deployment of personal computers to students through such bulk discounts, and that Michigan would rapidly fall behind if we did not do the same. The University negotiated an agreement with vendors to sell their wares when the students picked up their computers through the University.

Since the first major deliveries occurred early in the fall, these events were called the Fall Computer Kickoff Sale. It was quite a hit with the students, particularly when new systems such as the Macintosh appeared. The number of University students acquiring their own computers began to increase rapidly, stimulating both the College and the University to install appropriate networking capability in the residence halls and University buildings.

The final step in bringing CAEN to the level of sophistication Atkins had envisioned was made possible by a $2 million gift from General Motors that allowed Engineering to acquire over 350 high-end computer workstations, connected with high speed networks, to serve the advanced needs of students and faculty. The philosophy was simple: The College of Engineering was determined to stay always at the cutting edge, but with a very strong service focus. It sought to remove all constraints on computing, with no limit whatsoever on student and faculty use. The College went with a multivendor environment, moving with whatever technology was most powerful.

Needless to say, these were highly controversial issues in the early 1980s, particularly at the University of Michigan. But as a result, by the mid-1980s the University could boast one of the most sophisticated computing environments in the world, a fact of major importance to recruiting outstanding faculty and students.

Today this computing environment continues to expand, growing to the capacity to support the 48,000 students enrolled in the University of Michigan.

A brief history of "computing"at UM and some lessons learned from it.(concerning the interplay between innovation in technology development, broad adoption, and meaningful use in service of UM mission). (Atkins, 2018)

I. Early UM innovations

1881 - Installed first telephone, five years after Bell invention. (An act of the Regents).
1901 - First EE course on telephone and telegraph
903 - Broadcast UM-Minnesota football game to AA residents via phone
1907 - May Festival orchestra concert broadcast to Detroit
1912 - The two separate telephone companies in AA merged ending the need to support two different, non-interoperable systems.
1929 - Change to a dial system
1934 - 1400 telephones on campus
Early telephone era
1919 - Purchased first key punch machines and began use for admin work

2. Tabulators and analog computers

1920-1925 UM President Marion Burton
1925-1929 UM President Clarence Little
1929-1951 UM President Alexander Ruthann
1930 - Began routine use of tabulator machines in Registrar's Office and Hospital
1949 - Analog computers introduced in instruction in aerospace Engineering (Prof. Bob Howe)
1951-1967 UM President Harlan Hatcher
b) 1951-1958 UMs first digital computer, MIDAC, developed and used.
c) 1953-1963 College of Engineering offers intensive short courses for scientists and engineers attended by people across the country. (Profs Carnahan & Wilkes)
d) 1954 - UM processed 2 million punch cards for the field trials for Salk polio vaccine
e) 1956 - Prof. Art Burks founded Logic of Computers group
f) 1957 - Communication Sciences grad program established in LSA. Later became a department and in early 1980s merged into EECS in Engineering. UG LSA program contines
1957 - EE Dept begins courses on digital computer design and application

3. 1950s

1959-1963 Ford Foundation funds UM to lead national initiative in computing use in undergrad engineering.
1959 - Acquired IBM 650 then IBM 704
1959 - Computing Center established under Graduate School. Later moved to OVPR.
1962 - ICPR established as social science data archives used by many universities. Continues as a leader today.
1965 - NSF funds "Computers in Engineering Education" grant at UM
1966 - MERIT computer network established between UM, MSU and Wayne State. (Three years before ARPANet.)
1968-1979 UM President Robben Fleming
1969 - ARPA Net (precursor of Internet) sends first message

4. 1970s

1971 - Computing Center moves to North Campus
1972 - Prof. Bennie Galler & students develop CRISP, class registration system
1973 - One of the first Computer Engineering degrees established.
1975 - PhD Student Bob Parnes develops CONFER, a pioneering conferencing system. The first "social media."

5. 1980s

1980-1987 UM President Harold Shapiro
1981 - UM widely adopts routine use of home grown email system call MESSAGE
1983 - College of Engineering launches Computer Aided Engineering Network (CAEN) to begin distributed computing era at UM (Duderstadt & Atkins)
1984 - UM begins R&D around digital libraries

with supportfrom NSF and industry. (Atkins, et.al). This work enabled later leadership by UM in piloting the Mellon JSTOR Project and UM leadership role in Google Books Project.

1985 - UM pioneers the concept of a "research collaboratory" - a laboratory without walls. Over a decade of sponsored research by NSF. A by product of software developed with CTools course management and project coordination system. (Atkins, et. al)

1984 - Doug Van Houweling becomes first Vice Provost for IT

1985 - Formation of Information Technology Division (ITD)

1985 - Large investment in fiber optic plant and extension of network to residence halls

1985 - First and largest ever MacIntosh "Truck Load Sale". Frequent interactions with Steve Jobs.

1985 - Institutional shared file system developed and deployed

1986 - Installation of new digital telephone switch with 27,000 lines

l987) UM MERIT team wins NSF award to establish and operate NSFNET to open Internet capability to all of higher ed. The explosive growth of NSF played a major role in the dominance of TCP/IP as the universal Internet protocol.

1988-1996 UM President James Duderstadt

1988 - MIRLYN computerized library catalog system launched

1989 - Angell Hall courtyard converted into computing access cluster

1989 - UM Library established Internet-based access to large text corporate (pre-Web, used X-Windows based browser and custom terminal-based application)

6. 1990s

1990 - Emergency phone system installed on campus

1990 - Tim Berners-Lee at CERN completes all the tools necessary for a working WWW.

1991 - NSFNET operated by UM was spun off to Advanced Network Services to enable both non-profit and commercial development.

1993 - Mosaic browser becomes widely available and enables explosion of WWW usage.

1993 - NSF Digital Library Initiative begun. UM was one of six major awards. The DLI also supported UM grad Larry Page (then at Stanford) on a research project that led to the core web page ranking technology for Google.

1994 - Wolverine Access launched and Library launched Humanities Test Initiative

1995 - Program for the Study of Complex Systems established

1996 - Jose-Marie Griffiths named director of new Information Technology Division (ITD)

1996 - UM adopts PeopleSoft client/server system for admin computing

1996 - UM Library Making of America project launched. http://quod.lib.umich.edu/m/moagrp/

1996 - UM leaders launch the Internet 2 project with 34 universities. Became a separate non-profit in 1997 with an administrative services support relationship with UM.

1996 - UM establishes the first School of Information

1997 - TULIP and later PEAK project between UM and Elsevier helped establish economic models for digital publishing and the field of digital information economics. (Mackie-Mason, et.aln)

1996-2001 UM President Lee Bollinger

1998 - UM pilots JSTOR Project with funding from Mellon Foundation. http://www.jstor.org

7. 2000s

2001 - James Hilton appointed Associate Provost for Academic Information and Instructional Technology Affairs

2002-2014 UM President Mary Sue Coleman

2003 - NSF issues major report Revolutionizing Scienceand Engineering Through Cyberinfrastructure

2004 - UM launches Google Books project (https://www.google.com/googlebooks/library/)

2006 - Deep Blue digital repository launched

2006 - Prof. John King appointed VP for Academic

Information. ITS and ICS merged.

2008 - UM leads establishment of HathiTrust (https://www.hathitrust.org)
2008 - Formation of Office of Research Cyberinfrastructure (ORCI) reports to Provost and VPR in partnership with ITS.(Atkins). FLUX facility established.
2009 - Laura Patterson appointed Chief Information Officer and Associate Vice President for Information and Technology Services (ITS)
2010 - IT Council formed with IT investment prioritization based on mission-driven emphasis and multi-stake holder perspectives.
2012 - ORCI evolves into ARC under leadership of Prof. Eric Michielssen. Continued enhancement of infrastructure plus major programmatic initiatives (MICDE, MIDAS, expanded CSAR.) Has brought national recognition and praise.
2013 - James Hilton appointed Dean of Libraries and Vice Provost for Digital Educational Initiatives
2014 - UM President Mark Schlissel

Some lessons and observations from this history

UM has accepted the obligation, for leadership in IT innovation and its transformative use in learning/ teaching; research/discovery

1. The University of Michigan is unique in having the quality of top privates and the scale and disciplinary breadth of large publics, so both type institutions must pay attention to what we do.

2. UM finds, support sand disseminates great Innovation by individuals and units. It support/ protect agents of change where ever they are. We nurture virtuous cycles between IT deployment and innovative use pg vyberinfrastructure is nurtured - not built. It invest both external and internal funds in complementary ways.

3. UM is both a provider of research and object of R&D to understand how IT best serves its mission. It promotes a culture of continuous experimentation.

4. Much of the real innovation occurs in the units so be careful with too much centralization. Recognize need for optimal redundancy especially in supporting research and newmethods for learning.

5. Top leaders hopefully should see IT as a strategic asset, not just as a costly problem. It is part of the solution to the question of how research universities will thrive into the future given so many forces of change.

6. Leaders of IT organizations focusing on directly serving the academic mission should themselves be academics (with demonstrated management expertise). Administrativcomputing should be clearly positioned as a service to the academic mission, not an end in itself.

7. Need to recognize the role of IT in being "prescriptive" in some applications - i.e. constraining what can be done; and being"permissive" in other applications to enable lots of choice and nnovation. A university needs a spectrum of policies, appropriately applied.8. Lots of opportunity for more cooperation and synergy between "campus" and the health system but must be aware of item 7, above.

9. If an enterprise Chief Information Officer is established, please provide them with substantial resources that can be used to nurture synergisticactivities with schools and colleges. Respect the UM culture of strong autonomous schools and colleges but empower the CIOto add value and do deals for the common good. ACIO for UM should have real resources, not just make and enforc erules and monitor compliance.

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Universitas

Chapter 4

The Internet

One of the most important technologies in today's world is the Internet, which not only connects most of the world's people but also provides them with access to vast knowledge resources.

The first major computer network was the ARPANET developed in the 1960s and 1970s by the Department of Defense and based on packet-switching technology. and the TCP/IP protocol suite developed by Robert E. Kahn and Vint Cerf. Similar technology was utilized by Michigan's MERIT computer network. Yet these early networks were restricted by security (ARPANET) or geography (MERIT) and not available to the computing and communication needs of the broader scientific community. EDUCOM, the organization of universities working to adopt such technologies, was founded in Ann Arbor in 1964.

The first major steps to build a broadly available network, NSFNET, was launched in the 1980s by the National Science Foundation as a technology to connect scientists to its new supercomputer centers. This evolved rapidly during the 1990s into the Internet, clearly one of those technologies that has truly changed the world by connecting the people not only with others but with vast knowledge resources.

Yet the creation of the Internet and its early evolution during the 1980s and 1990s can be traced in large measure to the University of Michigan to an effort led by Douglas Van Houweling, while serving as the University's vice provost for information technology. President Harold Shapiro had created the position of Chief Information Officer and recruited Van Houweling from Carnegie Mellon, believing it critical to the University's efforts to solidify and extend its already substantial computer standing.

Van Houweling led a successful effort, based upon Michigan's early experience in building and operating the state's Merit computer network,the University-wide time sharing Michigan Terminal System for students and faculty, and the Computer Aided Engineering Network developing for the College of Engineering. With his own experience in computer system leadership at Cornell and Carnegie Mellon, coupled with exceptional leadership skills capable of building teams coupling together universities, industry, and federal agencies, Van Houweling was well-suited to responding to a major competition the National Science Foundation launched in 1984 to build a computer network to link scientists to its new supercomputer centers.

Douglas Van Houweling

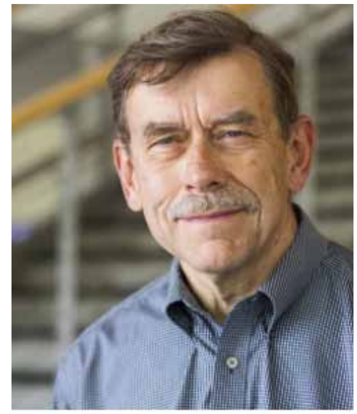
Ironically, however, the University's success in leading the effort to build the Internet came on the heals of its failure to win one of the grants to build a supercomputer center for the National Science Foundation, despite submitting one of the most highly ranked proposals for this effort.

The NSF Supercomputer Competition

During the mid-1980s, the National Science Foundation launched a competition to award grants to several universities to build several major supercomputer centers to serve the scientific community. The University of Michigan was well positioned to respond to this effort, since not only did it have many faculty members experienced in using the supercomputers at national laboratories such as Los Alamos and Livermore, but its MTS time-sharing computer system had used state-of-the-art computers provided by companies such as IBM and Amdahl. It also had considerable experience in providing broad access through its MERIT computer network, based on technologies similar to those used by ARPANET , then the nation's most powerful network based on protocols such as TCP/IP.

Since Amdahl had recently designed what was then the fastest supercomputer in the world, the Amdahl 1200, Michigan built its proposal to the NSF based on this technology. Because of its record of achievement providing time-shared computing to a large user base and the technical excellence of the Amdahl computer, the UM proposal was competitive and made it to the final site selection stage. However despite being ranked as the second highest of the proposals, the NSF declined it a center for the simple reason that the Amdahl 1200 supercomputer was actually built by Fujitsu in Japan, and the NSF leadership was disinclined to support an American network built upon Japanese technology. (When Duderstadt learned of this political decision, he arranged with the White House to be appointed to the National Science Board, the governing body for the NSF, which he was later to chair in the 1990s.)

Despite NSF's political decision to decline its competitive proposal, the University decided to invest its own resources in scientific computing, including the hiring of consultants who could help scientists access and utilize supercomputers for their research. The growing importance of scientific computing to complement the conventional areas of theory and experiment was becoming apparent across the United States, with well-funded NSF supercomputing centers at the University of California San Diego (UCSD), University of Illinois Urbana-Champaign and later the University of Pittsburgh. University of Michigan administrators decided to create a unit in Ann Arbor that would attract faculty with common interests in scientific computing who could go after funding and bring in computing resources. As one of the University's leaders in high-performance computing, William Martin was a natural choice to lead this effort and, in the late 1980s, he became the founding director of the Laboratory for Scientific Computing (LaSC).



William Martin

With John Boyd of Atmospheric, Oceanic and Space Sciences, Martin helped initiate a unique, and widely emulated, doctoral program in Scientific Computing. The program was, and continues to be, based on the principle that scientific computing is an enabling technology and not a discipline in its own right, so students who elect this program must first have a home department. They must elect courses in numerical analysis and scientific computing applications, and their thesis must be related to scientific computing in their discipline. The name of the student's degree is then formally appended with "... and Scientific Computing." Over 200 students have graduated from UM with this designation, representing 20 different departments across the University.

Leveraging the presence of the LaSC, the active research interests of faculty in Electrical Engineering and Computer Science and the support of the College of Engineering, Martin spearheaded a grant to the NSF in 1992 to obtain an nCUBE parallel computer. The NSF awarded a $2 million grant, and Martin became the founding director of the Center for Parallel Computing (CPC) that was set up to operate and maintain the nCUBE and provide access to UM users.

The NSF opened up a second competition for supercomputer centers in the late 1990s that would not only provide access to the largest supercomputers but also provide expert consultation and access to smaller systems (e.g. clusters) that were beginning to be used at the time. As a result of UM's track record with the LaSC and operating and maintaining the nCUBE system, UM was invited to join UCSD in a multi-university proposal, the National Partnership for Advanced Computational Infrastructure (NPACI). If awarded, the NPACI would fund a large computing platform at UCSD and smaller "mid-range" systems at the University of Texas at Austin and UM. Martin served as the principal investigator for the UM component of the UC San Diego proposal.

The NPACI proposal was funded for eight years and supported consultants who assisted users. The computing clusters totaled over 1,000 cores by the time the grant ended in 2005. In 2002, the CPC and the LaSC were merged into one unit, the Center for Advanced Computing (CAC), and Martin became the first director.

Scientific computing at UM continued to grow under new leadership and has evolved, became the Michigan Institute for Computational Discovery & Engineering (MICDE). The MICDE now serves as the focal point for the wide spectrum of research in computational science and engineering across the University.

The New NSFNET

With a group of supercomputing centers now in place—and a growing number of NSF-supported regional and local academic networks now operating across the country—the NSF needed to develop a better, faster network to connect them. Its NSFNET, operational in 1986, was at first modestly effective. But the huge surge in traffic seeking access to the supercomputer centers quickly swamped its existing infrastructure and frustrated its users.

It rapidly became apparent that the existing NSF computer network was woefully inadequate to handled the major increase in network activity created by the new supercomputer centers. Hence in 1987 the NSF solicited bids for an NSFNET upgrade, and the University of Michigan, with Van Houweling's leadership, was prepared to respond.

The MERIT team led by director Eric Aupperle and Douglas Van Houweling as chair of the MERIT board and UM CIO—who had been discussing precisely this kind of a network with the NSF for several years—were ready to respond. After the MERIT board agreed to join the project, Van Houweling approached his well-established contacts at IBM seeking their participation in the NSFNET project by building the hardware for the network and providing the network management. IBM, in turn, approached MCI, a telecommunications company to provide the transmission circuits for the NSFNET backbone at reduced rates. With these commitments in place, Michigan Gov. James Blanchard agreed to contribute $1 million per year over five years from the state's Michigan Strategic Fund.

Eric Aupperle

In the past such network technologies had been dominated by companies such as AT&T. Hoewevver Van Houweling felt strongly that a university was better positioned to build a network that would not only provide the connectivity for public activities such as research and education, but that Michigan's experience with the MERIT network gave them the capability to rapidly expand the new NSFNET to meet scientific needs.

As Associate and then Interim Dean of the College of Engineering, Dan Atkins strongly supported this effort, concerned that if the University did not step up, the Internet could have ended up as a much more closed environment that was segmented between telecommunications companies.

In November of 1987, Van Houweling received unofficial word that the National Science Foundation (NSF) had accepted his group's proposal to upgrade an overloaded NSFNET backbone connecting the nation's handful of supercomputing sites and nascent regional computer networks. However winning the competition for the new NSFNET was only the first step. Van Houweling's team now had to design and build the new network.

Building the Internet

The successful Merit proposal to NSF for the "new" NSFNET committed to creating an operational network by August 1988, so Van Houweling's team had to move fast, with the assistance of IBM and MCI as their corporate partners. It would have to be built using existing technologies capable of the high-speed connectivity that users would demand from the new supercomputer centers. It also had to be capable of rapid expansion to meet this growing demand from 13 regional networks and supercomputer centers along with more than 170 campus networks.

Key in this effort was to provide network routers capable of meeting the speed and capacity needs of the network. The new network first used a faculty-designed router (nicknamed the "Fuzzball") from the University of Delaware capable of 56 kilobits per second. But soon this had to be replaced with technology developed by their corporate partners at 1.5 megabits to handle the rapidly growing demand for connectivity with the new NSFNET. They were able to create a functioning network within eight months, meeting the goals set in their proposal to the NSF, a truly extraordinary achievement

The Merit team was surprised when their new NSFNET began to experience a growth in demand at a rate of 10% per month, which would continue for years as it became the fastest and most reliable computer network in the world. Although initially designed to support the NSF supercomputer centers, usage rapidly broaden to include the broader scientific community and then beyond to the general public as it became the largest backbone network in the United States providing connectivity to the world. As Dan Atkins observed, "The adoption of the open protocols of the NSFNET went up exponentially, and it created what we would now call a "vital effect", where everybody wanted it, including the commercial world".

Together with their partners IBM and MCI, the Merit NSFNET remained a state-based nonprofit organization. Hence it was soon clear that another organization was needed to handle the exploding demand of the world's fastest (T3) high capacity network. Hence a new organization, the Advanced Network Services (ANS), was formed that was able to create a for-profit to enable commercial traffic. Not surprisingly, there were complexities, such as the federal regulations on the use of this technology funded by a government agency, i.e., the National Science Foundation. Regional networks felt constrained by NSF's Acceptable Use Policy, requiring purely commercial traffic. Eventually following Congressional hearings and a report by the NSF Inspector General, in 1992 federal legislation expanding the regulations on NSFNET to include commercial traffic.

Van Houweling discussing NSFnet at EDUCOM

New software developments such as Tim Berners-Lee's World Wide Web and new applications such as e-mail, instant messaging, social networking, and online shopping stimulated further growth and evolution until the ANS transferred the project to commercial management by AOL in 1993. This network activity would grow from 1% of telecommunication traffic in 1993 to 50% in 2000 to over 97% today.

Internet 2

University activities in the development of digital information and communications technology continued throughout the 2000s, although there were some minor setbacks. A key successor was the Internet2 project, founded by Douglas Van Houweling to develop a consortium of institutions to build the next generation of the Internet.s

Unfortunately, with the arrival of a new Michigan president, Lee Bollinger, and his restructuring of University's administrative staff, support of the

Internet 2 no longer was regarded as a priority. After further difficulties in receiving adequate support from Michigan, the headquarters of Internet2 was moved from Ann Arbor to Washington, DC.

Internet2 initially provided a high-performance network environment for the US research and education community that was optimized to meet the needs of research, teaching, learning, clinical, and outreach missions of that community. But today Internet2 enables the development and deployment of new network, middleware, and applications technology, services, and protocols.

Looking Back...and Looking Ahead

With the arrival of Doug Van Houweling and the leadership and experience he provided, the University (and MERIT) were well positioned to respond with partners IBM and MCI to an RFP from NSF to build a broad scientific network, NSFnet, that would link together the NSF supercomputer centers with a national network for research and education. Soon other networks such as ARPAnet, Bitnet, and CSnet were swept into this "internetwork", and of course, this became the backbone of the Internet–"Internet One'–that has so transformed our world today.

Of course, in those early days few had any idea that a small regional network would grow into an effort that would transform the world. Who could have anticipated the emergence of killer applications such as the WWW or the browser that would trigger both an avalanche of users (increasing at a rate of 15% per month during the 1990s) or applications.

Bill Wulf, one of the first directors of NSF's CISE, observed that looking back over the history of NSF he can find few Foundation efforts that come close to matching the extraordinary impact on research, education, and society than NSFNET and its successor, the Internet. This took Van Van Houweling's exceptional leadership and the experience of the Merit team led by eric Aupprerle. The MERIT history is also an extraordinary story that future historians will rank with Gutenberg, Bell, and Ford as a technological effort that changed the world.

Internet 2 Connecting the World

Lessons Learned

The Internet's governance remains a controversial subject. Is t his free enterprise? Or is it subject to national laws or international organizations. To what degree can it be self-governing, e.g., as ICAAN, the Internet Society, a permissive national and internationa environment?

Kevin Kelly notes that in the eyes of the National Science Foundation (which ran the internet backbone), the internet was funded for research, not commerce. "In what seems remarkable naiveté now, the rules favored public institutions and forbade "extensive use for private or personal business. The techy administrators thought of their work as noble, a gift to humanity. They saw the Internet as an open commons, not to be undone by geed or commercialization. In the eyes of the NSF, the internet was funded for research, not commerce. In what seems remarkable naive now, the rules favored public institutions and forebid "extensive use for private or personal business." (Kelly, 2010)

The higher education and research community has enormous capability, but ONLY in partnership with government and industry. National policy is critical here since it provides seed capital and can remove regulatory barriers. Community support is also critical. But not-for-profit organizations are key!

The Development and Future of the Internet
NSFnet and Michigan
A Timeline

Douglas Van Houweling

1958: Advanced Research Projects Agency (ARPA)
- 1965 CONCOMP at UM funded
- 1967 ARPANET funed
- 1972 ARPANET demo in DC
- 1974 TCP/IP standard published

1964: EDUCOM founded at UM
1967: LBJ "networks for knowledge" speech:
1968: Michigan Educational Research Information Triad (Merit)
- 1969: State of Michigan and NSF funding
- 1971 MERIT network demonstrated

1979: CSNet founded
1980: Merit/ARPANET connection
1985: UM loses supercomputing competition
- (one of strongest proposals but based on a Japanese machine...)

1986 NSF creates NSFNET based on TCI/IP
- 56 kilobit, Fuzzball routers from Delaware
- (developed by Dave Mills UM CONCOMP operated by Hans-Werner Braun at Merit

1987: Merit wins NSFNET Network Backbone award
- NSF $15 M
- UM $5 M
- IBM $50 M router hardware and software
- MCI 410 M telecommunications circuits
- Connected the 5 supercomputing centers and 8 regional networks
- 2-tier model: Merit in MI, NYSERNET in NY

July 1988: Production service
- T1 (1.5 megabit links)
- MCI digital circuits (500 kilobits/s to start)
- 15% per month growth in demand

1989: Time Berners Lee invents HTML and the World Wide Web
- NYSSERNET establishes PSINet

1990: Advanced Network Services (ANS) founded
- Partnership
  - Merit: NSF Grant
  - IBM MCI, Nortel: $3 M donations
  - Headquartered in Armok (IBM
- Usenic establishes UUNET

1991: 45 Megabit network operational
1993 NSF allows commercial access to NSFNET
1994 ANS create ANS Core for profit subsidiary
1995 ANS-CORE sold to AOL
- AOL establishes center in Ann Arbor
- ANS uses proceeds for R&D
- HigherEd moves to commercial provide
- Regional networks acquired
- NSF launches high performance Network System through MCI (vBNS)
- World Wide Wait
  - NSFNET at 1 MB
  - Now 9600 baude modem faster

1996 Chicago meeting to found Internet II
- 34 universities
- 425 K/y dues, $500 K/y network cost
- Project of EDUCOM

1997 110 Universities
- Using vBNS at 155 MB/s

1998 Abilene Natiional Backbone Network
- 2.5 Billion bits/sec
- Partners Qwest, Cisco, Northern Telecom

2002 Upgraded to 10 billion bits/sec
2005 Internet2 Network
- Replaces Abilene backbone network
- 13,000 mile dedicate fiber pair
- Up to 40 gigabit wves
- Hybrid optical and IP network
- Fiber dedicated to Internet 2
- Infrastructure for multiple networks
- Plarform suppots both services and research

2012 Generation Interenet2
- 18,000 mile dedicated fiber pair
- Up to 88 100 gigabit waves (88 terabits)
- Hybrid optical, IP, OpenFlow network
- $66 M Dept of Commere grant
- All facilities capitalized by Internet2
- Combines ESNet with Intrernet2 network
- US Unified Community Anchor network

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Chapter 5

Cyberinfrastructure

In the late 1980s, the growth of computing power and connectivity was changing the face of science and engineering. The rise in power, connectivity, content, and flexibility was so rapid that it was dramatically reshaping relationships among people and organizations, and quickly transforming our processes of discovery, learning exploration, cooperation, and communication. It permitted us to study vastly more complex systems than previously possible and provides a foundation for rapid advances in understanding of learning and intelligent behavior in living and engineered systems. Today's challenge is to realize the full potential of these new resources and institutional transformations.

While the underlying technology of our age is certainly digital in nature, the real opportunity is in its extreme connectedness: people -to -people, to information, to instruments, to facilities, to arrays of computational tools. While the Internet technology described in the previous chapter involved the technology for social media and building organizations such as Google, Facebook, and Amazon, this was only one element of an increasing powerful environment, including advanced computation, theories, simulation, data mining, and even artificial intelligence. It is becoming increasingly clear that the world is approaching an inflection point similar to the Renaissance of the Middle Ages when the tools provide by advances in knowledge were becoming available to ever expanding communities.

The new word for this integrated technology became *cyberinfrastructure*, the term used to describe hardware, software, people, organizations, and policies. As stressed by Dan Atkins, one of the leaders of this technology both at the University of Michigan and the National Science Foundation, this term is used to emphasize that we are not just talking about technology, but rather an ecosystem of people, organizations, and technology that provides a true infrastructure on which to build and deploy services. Infrastructure is the basic physical and organization structure needed for the operation of a society or enterprise. With Atkins leadership, first the University of Michigan and then the United States has played an important role in developing key cyberinfrastructures for each of these eras such as digital libraries , schools of information, and collaboratories

Today cyberinfrastructure technology has created a remarkable convergence of disciplines, social, economic, legal, behavioral and reflected by the simple fact that computers and social scientists needed each other. An early example of this effort was the development of the *collaboratory*: connecting people with technologies and other people. Later this theme led to digital libraries and other forms of cyberinfrastructure enabled research and learning:

Early Developments of Cyberinfrastructure

The early phases of cyberinfrastructure actually go back over many decades, with the development of the telephone, tabulators, and stand-alone computers. Later development of mainframe computers with remote time sharing, programming languages such as FORTRAN and CONFER eventually let to distributed computing and the early computer networks and such as MERIT and ARPANET.

These cyberinfrastructures soon began to share learning through developments such as Sakai, OpenCourseWare, Google Book Project, the Hathitrust and collaboratories that were early examples of a rapidly growing effort to open up opportunities for learning and scholarship to the world through cyberberinfrastructure by adopting the spirit of open source software development, putting previously restricted knowledge into the public domain and inviting others to join both in its use and development.

Open source, open content, open learning, and other “open” technologies even raise the possibility of developing the scaffolding on which to build truly global universities–what Charles Vest , president of MIT, termed the “meta” university. Vest suggested that through the array of open paradigms, we were seeing the early emergence of a “Meta University” – a transcendent, accessible, empowering, dynamic, communally-constructed framework of open materials and platforms on which much of higher education world wide can be constructed or enhanced. Cyberinfrastructure provided the technology and the open paradigms use it to distribute knowledge and learning opportunities to the world.

As one of the early examples of such “meta” or “virtual” universities. In 1996 the University created a new institution, the Michigan Virtual Auto College, designed to explore the implications of digital technology for higher education. This was a collaborative effort among the University of Michigan, Michigan State University, the State of Michigan, the state’s other colleges and universities, and the automobile industry. It was formed as a private, not-for-profit, 501(c)3 corporation to broker technology-enhanced courses and training programs for the automobile industry, including the Big 3 and Tier 1, 2, and 3 providers. Duderstadt was one of the leaders of this and later became its president for a brief period.

MVAC served as an interface between higher education institutions, training providers, and the automotive industry. It worked to facilitate the transfer of credits between and among institutions to facilitate certificate and degree attainment for those participating in courses and training programs offered under its auspices. MVAC offered courses and training programs, ranging from the advanced post-graduate education in engineering, computer technology, and business administration to entry level instruction in communications, mathematics, and computers. Capitalization for MVAC was provided by members of the partnership: the State of Michigan ($5 million),

Michigan Virtual University

the universities ($2 million), and the automobile industry ($5 million). However it was expected that the effort would rapidly become self-supporting, based on student fees. The schedule for the MVAC was an aggressive one, with formal incorporation in fall of 1996, delivery of the first array of pilot courses by February, 1997 and a full curriculum in place by Fall of 1997. The MVAC paradigm was sufficiently successful that it broadened its curriculum into a full range of undergraduate curricula and was renamed the Michigan Virtual University in 1998, with participation by both public universities and community colleges throughout the state and continues to provide online learning opportunities throughout the state. This was a precursor of the leadership provided by the University in distributed learning technologies,.

The NSF Cyberinfrastructure Committee

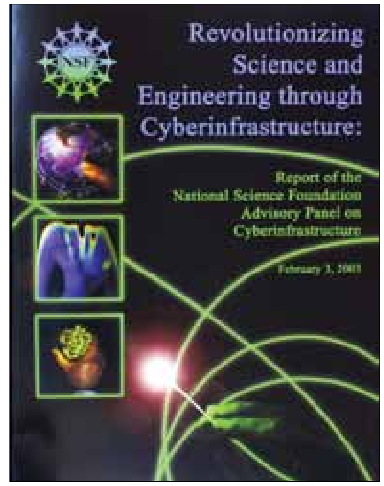
In the early 2000s, Dan Atkins chaired a blue ribbon advisory committee for the National Science Foundation on the growing importance of information and communications technology on research and education.

The conclusion of their report is important:

“A new age has dawned in scientific and engineering research, pushed by continuing progress in computing, information, and communication technology, and pulled by the expanding complexity, scope, and scale of today’s challenges.

The capacity of this technology has crossed thresholds that now make possible a comprehensive

Dan Atkins



NSF Cyberinfrastructure Study

'cyberinfrastructure' on which to build new types of scientific and engineering knowledge environments and organizations and to pursue research in new ways and with increased efficacy.

The emerging vision is to use cyberinfrastructure to build more ubiquitous, comprehensive digital environments that become interactive and functionally complete for research communities in terms of people, data, information, tools, and instruments and that operate at unprecedented levels of computational, storage, and data transfer capacity. Here one should stress the terms: comprehensive, functionally complete, and ubiquitous.

The inherent complexity, multi-scale, and multi-science nature of today's frontier science challenges

The accompanying requirement for a multi-disciplinary, multi-investigator, multi-institutional, and perhaps international approach.

The high data intensity and heterogeneity from simulations, digital instruments, sensor nets, and observatories.

The increased scale and value of data and demand for semantic federation, active curation, openness, and long-term preservation.

And the need to engage more students in high quality, authentic, passion-building science and engineering education."

Hence the importance of their final observation: "This digital revolution will pose considerable challenges and drive profound transformations in existing organizations such as universities, national and corporate research laboratories, and funding agencies. Here it is important to recognize that the implementation of such new technologies involve social and organizational issues as much as they do technology itself. Achieving the benefits of IT investments will require the co-evolution of technology, human behavior, and organizations."

Like other infrastructure — the electric power grid, the national highways — cyberinfrastructure combines complex elements to create a dynamic system. It eclipses its many hardware and software components to enable people and their interactions with technology to become the central focus. At the heart of the cyberinfrastructure vision are cultural communities that support peer-to-peer collaboration and new modes of education. They are distributed-knowledge communities in an institutional context, not of bricks and mortar like the traditional university, but rather virtual organizations that work across institutional boundaries — and ultimately around the globe.

To create and use cyberinfrastructure, learning and work-force development initiatives will be the most important requirements. Cyberlearning and collaboration augment the more traditional learning environments. They offer additional modes of interaction among people, information, and facilities. This is no small advantage in an age when bringing people, information, and facilities together in the same place at the same time — be it the laboratory, classroom, library, or museum — is probably the most expensive of the various ways we collaborate and

Atkins at NSF

NSF Division of Cyberinfrastructure

educate. For just this reason, there is an increasing trend toward international collaboration in developing large research facilities that are just too costly for every nation to replicate. When these cyberinfrastructure tools are integrated into virtual networks, they become community resources, on both a national and a global scale.

As cyberinfrastructure evolves, it will become an integral part of research and education across the board, including the humanities and the arts. Leadership in cyberinfrastructure may well become the major determinant in measuring pre-eminence in higher education among nations.

Certainly other nations are acting with determination to realize their own visions of the future, including how to educate the scientists and engineers who are central to technology-driven societies. Every nation now knows that investments in education, research, and research infrastructure are the key elements that are driving the global economy in this knowledge-intensive era.

While the coming cyberinfrastructure revolution will further flatten and shrink the world, it will also reward those who are agile and adept at change. Charting a course for this second revolution is a task for here and now. It will require passion and persistence to propel us to success.

It is certainly not a time for hesitation or procrastination. We simply must meet the challenge of surmounting our insurmountable opportunities!!! Today technology has created a remarkable convergence of disciplines, social, economic, legal, behavioral and reflected the simple fact that computers and social scientists needed each other. An early example of this effort was the development of the collaboratory: connecting people with technologies and other people.

To quote Arden Bement, then director of the National Science Foundation:

"We are entering a second revolution in information technology, one that may well usher in a new technological age that will dwarf, in sheer transformational scope and power, anything we have yet experienced in the current information age.

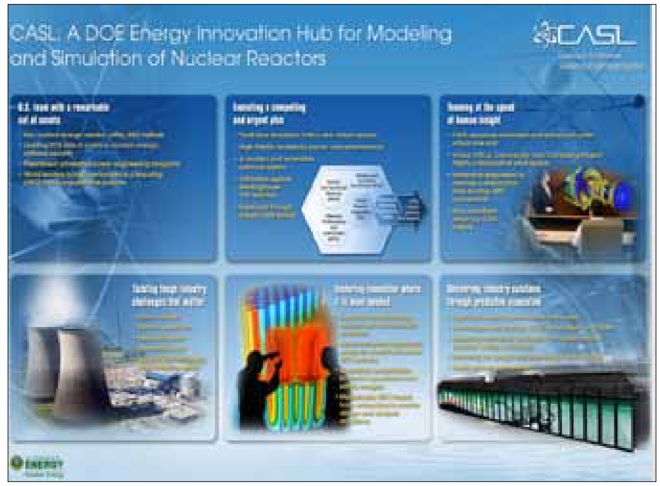
We are already intimately familiar with the first revolution, now well under way. Information, computer, and communications technologies have transformed nearly every aspect of our lives, creating entirely new opportunities and challenges, and trailing some inevitable surprises in their wake.

The engine of change for the next revolution is cyberinfrastructure, a comprehensive phenomenon that involves the creation, dissemination, preservation, and application of knowledge. It adds new dimensions that greatly increase transformational potential."

"The evolution of knowledge communities enabled by cyberinfrastructure will require extensive collaboration among individuals from all fields and institutions across the entire educational spectrum. In particular, universities must be responsible for initiating, developing, and supporting the lion's share of cyberinfrastructure.'

Bement responded to this opportunity by creating a new NSF Office of Cyberinfrastructure, and persuaded

Radar Installations for UARC Collaboratory



CASL Discovery-Innovation Hub

Dan Atkins to come to Washington to lead this effort (later succeeded by Ed Seidel). Jim Duderstadt would later chair its advisory committee.

Collaboratories

With increasing connectivity, barriers of space and time began to disappear as new forms of collaboration appeared allowing investigators to not only exchange ideas but to share widely dispersed instrumentation and data. Bill Wulf, president of the National Academy of Engineering, coined the term *collaboratory* to described "a center without walls, in which the nation's researchers can perform their research without regard to physical location, interacting with colleagues, accessing instrumentation, sharing data and computation resources, and accessing information in digital libraries".

More rigorously, today the *collaboratory* is defined as "a system which combines the interests of the scientific community at large with those of the computer science and engineering community to create integrated, tool-oriented computing and communication systems to support scientific collaboration."

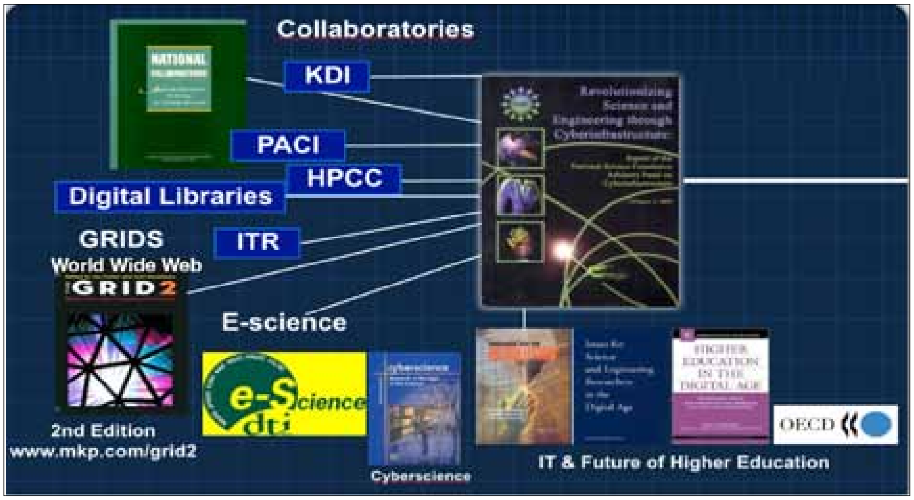
An interdisicplinary group was formed at the University of Michigan by Dan Atkins and Tim Killeen (later AD for the GEO drectorate at NSF) to demonstrate this concept by proposing the creation of a collaboratory for ionispheric measurements in the Artic. Scientists had long had the problem of the expense to get to Greenland where their instruments were. They viewed this as telescience, but along the way they discovered new characteristics of such collaboratory efforts.

These scientists studied "space weather", the interaction of solar wind from the Sun with Earth's magnetic field causing the aurora borealis and occasional destruction of space born satellites. Their principal ground-based research was located on the southwest coast of Greenland where they would travel by way of Demark several times a year for data gathering campaigns, hoping that eruptions would produced interesting interactions for them to observe.

Using human-centered iterative design metods, the team evolved an experimental colalboratory that enabled distributed teams to conduct data campaigns remotely. Teams worked in real-time to tune be the suite of instructions and steer them, although managing the network connection to Greenland was a major challenge.

The UARC collaboratory was sufficiently successful that a second phase was launched, the Space Physics and Aeronomy Reserach Collaboratory (SPARC) involving an even broader international community of atmospheric scientists. The collaboratory enabled the international sharing of remote instructions and the expertise of instrumentation designers and operators; it enabled more science by rapid response not requiring physical travel; it linked together isolated and diverse instructions: and it enable more student participation and learning.

As a variation on the collaboratory concept, in 2005 new forms of research centers known as *discovery innovation institutions* were proposed by the Brookings Institution working with the National Academy of



Other Examples of Collaboratories

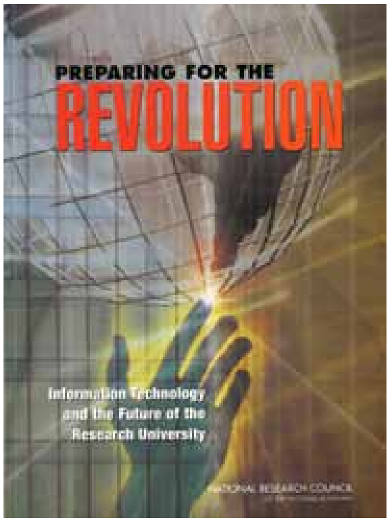
Engineering. These centers would be established on the campuses of research universities to link fundamental scientific discoveries with technological innovations to create products, processes, and services to meet the needs of society. With the participation of many scientific disciplines and professions, as well as various economic sectors (industry, government, states, and institutions of higher education), discovery-innovation institutes would be similar in character and scale to academic medical centers and agricultural experiment stations that combine research, education, and professional practice and drive transformative change. As experience with academic medical centers and other large research initiatives has shown, discovery-innovation institutes would have the potential to stimulate significant regional economic activity, such as the location nearby of clusters of start-up firms, private research organizations, suppliers, and other complementary groups and businesses.

As yet another variation on the collaboratory theme, in 2008 a project supported by the Brookings Institution proposed the concept of *discovery-innovation hubs*, in which the fundamental research conducted by universities would be refined by the technical capabilities of the United States network of national laboratories and then implemented by industry. The first set of discover-innovation hubs was launched by the Department of Energy in 2010. One of the largest and most successful such efforts was the Consortium for Advanced Simulation of Light Water Reactors (CASL), led in part by the University of Michigan. (Martin, 2010)

A final example of collaboratories was the Learning Health System collaboratory formed at Michigan as a "cyber-social learning system" where medical research data could be rapidly shared with not only practicing physicians but also with students in the health sciences. Here the fundamental challenge is the fact that medical students graduating in the year 2020 will enter a world with 50 times as much health data as there was when they applied to medical school. Yet, at today's rate of health care quality improvement, and with today's decade-long lethal lag between between new knowledge discovery and its widespread application, it would take 35 years for quality to double. "Here the challenge using the collaboratory structure to couple directly the rapid pace of knowledge creation for understanding and treating medical issues with both practicing physicians and medical students. These cyber-social learning systems have become an important asset of contemporary medicine."

Imagine a time in the near future where anyone with even a modest Internet connection has access to all of the recorded knowledge of our civilization along with ubiquitous learning opportunities. Imagine further the linking together of a substantial part of the world's population with limitless access to knowledge and learning opportunities enabled by rapidly evolving cyberinfrastructure increasing a thousand-fold in power every decade.

While science fiction continues to entertain us with the possible emergence of superhuman artificial



intelligence, of far more likelihood and interest is the emergence of a new form of collective human intelligence, as billions of world citizens interact together, unconstrained by today's monopolies on knowledge or learning opportunities.

Perhaps this, then, is the most exciting vision for the future of the university–no longer constrained by space, time, monopoly, or archaic laws–but rather unleashed by cyberinfrastructure to empower the emergence of a new global civilization of humankind.

The IT Forum

IT Forum

- James Duderstadt, President Emeritus, University of Michigan (Forum chair)
- Daniel Atkins, Professor, School of Information, University of Michigan
- John Seely Brown, Chief Scientist, Xerox Corp.
- Jared Cohon, President, Carnegie Mellon University
- Stuart Feldman, Vice President, Internet Technology IBM
- Nils Hasselmo, President, Association of American Universities
- Brian Hawkins, President, EDUCAUSE
- Shirley Ann Jackson, President, Rensselaer Polytechn Institute
- Sidney Karin, Professor of Computer Science and Engineering, University of California, San Diego
- Kevin Kelly, Editor-at-Large, *Wired*
- Shirley Strum Kenny, President, Stony Brook University
- Susanne Lohmann, Director, Center for Governance, University of California, Los Angeles
- Anne Margulies, Executive Director, OpenCourseWare, Massachusetts Institute of Technology
- Michael McRobbie, Chief Information Officer, Indiana University
- Diana Oblinger, Vice President, EDUCAUSE
- James O'Donnell, Provost, Georgetown University
- Marshall Smith, Professor, School of Education, Stanford University, and Program Officer for Education, Hewlett Foundation
- Lee Sproull, Professor, Stern School of Management, New York University
- Doug Van Houweling, CEO, University Corporation for Advanced Internet Development
- Robert Weisbuch, President, Woodrow Wilson National Fellowship Foundation
- Wm. A. Wulf, President, National Academy of Engineering (Program chair)

Clearly rapidly evolving information technology is rapidly expanding our capacity to generate, distribute, and apply knowledge, linking people, knowledge, and tools in new and profound ways.

It is driving rapid, unpredictable, and frequently disruptive change in existing social institutions.

The rapid evolution of digital technology will present many challenges and opportunities to higher education in general and the research university in particular.

Yet there was a sense that many of the most significant issues are neither well recognized nor understood either by leaders of our universities or those who support and depend upon their activities.

It was just such concerns that stimulated the National Academies to launch a major project to understand better how this technology was likely to affect the research university.

The first phase of the study was aimed at identifying those technologies likely to evolve in the near term (a decade or less) that might have a major impact on the research university and examining the possible implications of these technology scenarios for the research university.

The first finding was that the extraordinary pace of information-technology evolution is likely not only to continue for the next several decades, possibly even accelerating. Hence, in thinking about changes to the university, one must think about the technology that will be available in 10 or 20 years, technology that will be thousands of times more powerful as well as thousands of times cheaper. For example, current scientific computation is now at the hundreds of teraflop

IT Forum Discussions

level, with major initiatives such as IBM's Blue Gene and Michigan's own efforts in NSF petascale initiative soon to take us to petaflop levels. In fact, some are even beginning to think about exaflop machines at 10**18, roughly 100 times faster than the processing capability of the human brain.

The second finding was that the impact of IT on the university is likely to be profound, rapid, and disruptive, affecting all of its activities (teaching, research, service), its organization (academic structure, faculty culture, financing, and management), and the broader higher education enterprise as it evolves toward a global knowledge and learning industry.

An observation here: If change is gradual, there will be time to adapt gracefully, but that is not the history of disruptive technologies. As Clayton Christensen explains in The Innovators Dilemma, new technologies are at first inadequate to displace existing technology in existing applications, but they later explosively displace the application as they enable a new way of satisfying the underlying need. (Christensen, 2015)

The third finding stresses that although information technology will present many complex challenges and opportunities to universities, procrastination and inaction are the most dangerous courses to follow all during a time of rapid technological change. Attempting to cling to the status quo is a decision in itself, perhaps of momentous consequence.

More recently, the National Academies have extended this effort to involve directly a large number of research universities by creating a National Academy roundtable on information technology and research universities ("the IT-Forum") to track the technology, identify the key issues, and raise awareness of the challenges and opportunities.

While perhaps not enabling the level of strategic discussions that we had hoped, the IT Forum has certainly reinforced the good-news, bad-news character of digital technology. The good news is that it works, and eventually it is just as disruptive as predicted. The bad news is the same: this stuff works, and it is just as disruptive as predicted.

In one sense it is amazing that the university has been able to adapt to these extraordinary transformations of its most fundamental activities, learning and scholarship, with its organization and structure largely intact.

Yet if one looks more closely at the core activities of students and faculty, the changes over the past decade have been profound indeed. The scholarly activities of the faculty have become heavily dependent upon digital technology–rather cyberinfrastructure–whether in the sciences, humanities, arts, or professions.

And, as we have noted earlier, both student life and learning is also changing rapidly, as students bring onto campus with them the skills of the net generation for applying this rapidly evolving technology to their own interests, forming social groups, role playing (gaming), accessing services, and learning–despite the insistence of their professors that they jump through the hoops of the traditional classroom paradigm.

Here one might be inclined to observe that technological change tends to evolve much more rapidly than social change, suggesting that a social institution such as the university that has lasted a millennium is unlikely to change on the timescales of tech turns– although social institutions such as corporations have learned the hard way that failure to keep pace can lead to extinction.

Universities are highly adaptable organizations, tolerating enormous redundancy and diversity. It could be that information technology revolution is more a tsunami that universities can float through rather than a tidal wave that will swamp them.

Yet, while social institutions may respond more slowly to technological change, when they do so, it is frequently with quite abrupt and unpredictable consequences, e.g., "punctuated equilibrium". It could also be that the revolution in higher education is well underway, at least with the early adopters, and simply not sensed or recognized yet by the body of the institutions within which the changes are occurring.

It is certainly the case that futurists have a habit of overestimating the impact of new technologies in the near term and underestimating them over the longer term. There is a natural tendency to implicitly assume that the present will continue, just at an accelerated pace, and fail to anticipate the disruptive technologies and killer apps that turn predictions topsy-turvy. Yet we also know that far enough into the future, the exponential character of the evolution of Moore's Law technologies such as info-, bio-, and nano- technology makes almost any scenario possible.

In this spirit, then, perhaps we should end with a discussion that occurred with the AAU provost's workshop in 2004. While university presidents are reluctant to let speculation about the survival of the university on the table, not so with provosts, who were quite comfortable talking about very fundamental issues such as the values, roles, mission, and even the survival of the university, at least as we know it today. During this discussion it was pointed out during the 19th century, in a single generation following the Civil War, essentially everything that could change about higher education in America did in fact change: small colleges, based on the English boarding school model of educating only the elite, were joined by the public universities, with the mission of educating the working class. Federal initiatives such as the Land Grant Acts added research and service to the mission of the universities. The academy became empowered with new perquisites such as academic freedom, tenure, and faculty governance. Universities increased 10-fold and then 100-fold in enrollments. The university at the turn of century bore little resemblance to the colonial colleges of a generation earlier.

The consensus of discussions with the provosts suggested that we are well along in a similar period of dramatic change in higher education. In fact, some of our colleagues were even willing to put on the table the most disturbing question of all: Will the university, at least as we know it today, even exist a generation from now?

Disturbing, perhaps. But certainly a question deserving of very careful consideration, at least by those responsible for leading and governing our institutions!

The Balance of Responsibilities

The challenge of big data, big information, big knowledge and big (or at least adequate) wisdom: What do we need to do at the level of the campus and through broader communities and partnerships with government and industry? Perhaps we all need to set aside our competitive ways to join in the process of constructing curricula. We should join together to get a sense of what is needed in training or educating people in the big data world. That is what we are trying to do with our university resources perhaps such efforts of collaborating across institutions and agencies need to occur to address the challenges and opportunities of rapidly changing technology.

There was strong agreement with this theme of collaboration. Big data is a game in terms of how it informs the pursuit of science, builds the communities, creates new communities of practice, and opens up intellectual parameter space. It provides great opportunities for communities to exercise leadership. We all don't need to create new curricula unique to our home institutions, rather we can collaborate on such efforts.

A caution was offered about the way that we culturally struggle with cyberinfrastructure space. Although it is a sweeping generalization to suggest it, we are actually the wrong community to be asking how to run cyberinfrastructure. The skills and the ethos of the people who run infrastructure are very different from those of the people who do research. Of course there is a lot of important coupling and feedback between the two communities. We have struggled in cyberinfrastructure space given the rate of change and our ability to sustain our activities with the rapid changes in this technology. The timescale for cyberinfrastructure necessarily has to be longer than the research project. The notion of making 10-20 year commitments to things with the appropriate assessment is important. We cannot do it with 3-year initiatives. Then, too, there is the earlier issue the group discussed about the importance of craft. There are a whole set of issues about the necessary skill base and career path about people who operate infrastructure has to be sustainable. Finally, one must question whether the campus is the right unit of discussion for many of these topics. Of course many of these concerns are at the regional, national, and even global level. The larger the scale of investment, the larger the odds of hiring and keeping great people to do them. We should not think of cyberinfrastructure investment on these larger scales from the viewpoint of simply "I'll get my x-percent share."

Gerhard Klimeck noted that when he contemplated switching from JPL to Purdue to run NanoHub, he had reservations about Purdue really wanting to run Nanohub. Purdue was a great and supportive institution. But to run this more nationally he would rather have this run at a Google or Yahoo framework where his technical group could focus on things they were good at and not waste time trying to catch up in collaborative environments of Google docs. They knew how to run simulations, not build and sustain national enterprises. If forced to do both, it would be to the detriment of the research mission. NSF could play a significant role in helping research universities to interact in a more collaborative and strategic ways with technology vendors.

The question was raised about whether companies like Google and other technology providers have evolved to respond to the mission-critical nature of many research projects? The response from the Google participant was that such university efforts usually are not life-critical. An outage for a few minutes doesn't split a spleen. Security management is better than universities are likely to do on your own campus. If the "–ilities" (reliability, availability) are appropriate, use the vendor. But there was concern expressed that very young infrastructure companies like Google and Facebook were still immature in the way that they approached the provision of cyberinfrastructure for mission-critical applications (with university medical centers or proprietary research key examples).

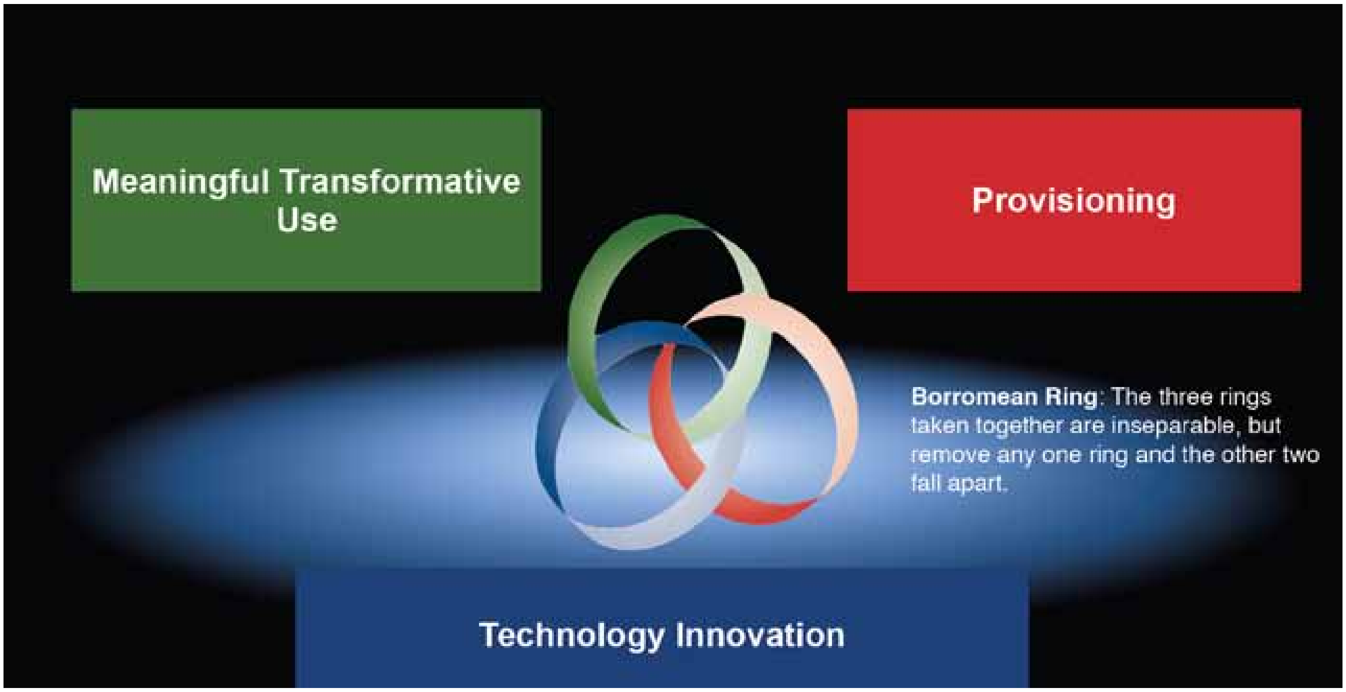
It was suggested that much of the challenge to universities involved the nature of research support. Companies have to recover true cost plus some profit margin. Most university infrastructure has implicit subsidies. Universities must expose these and be honest about what the cost is. We have to do the cost accounting clearly and appropriately, and then be prepared for technology services to reflect these true costs in their proposals–and expect to hold them accountable for deliverables.

Broadening the Recommendations

Dan Atkins provided a more fundamental description of this activity by using the mathematical concept of a Borromean Ring, where three rings looped together became inseparable, since removing anyone ring caused the other two to fall apart. He stressed that cyberinfrastructure depended upon such a structure with meaningful transformative use coupling to provisioning coupling to technology innovation.

Atkins weighed in with three observations: First, in the area of infrastructure, the focus should be on the problem and not the tool or the tool waiting for a problem. The relationship between tools and problems in the cyber world is more nuanced. In building the collaborator for ionispheric measurements in the Artic, scientists had a problem: it was getting expensive to get to Greenland. The solution was the Internet. They viewed this as telescience, but along the way they discovered new characteristics of such collaboratory efforts. It involves a process, a participatory design to create living specifications that then allow people to see next set of tools they need. There is a chicken and egg loop you need to understand and break if necessary to make progress.

Second, he wanted to repeat an earlier idea:



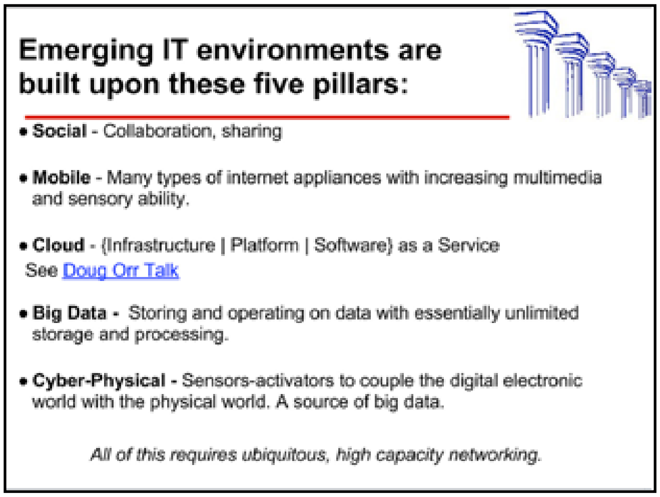
you really needed iterative participatory design between technologist, the end user community, and the assessment (guardians of the human-centered perspective). The system needs design to have embedded assessment and iterative design to make it better. He illustrated this with the Bromian Ring concept.

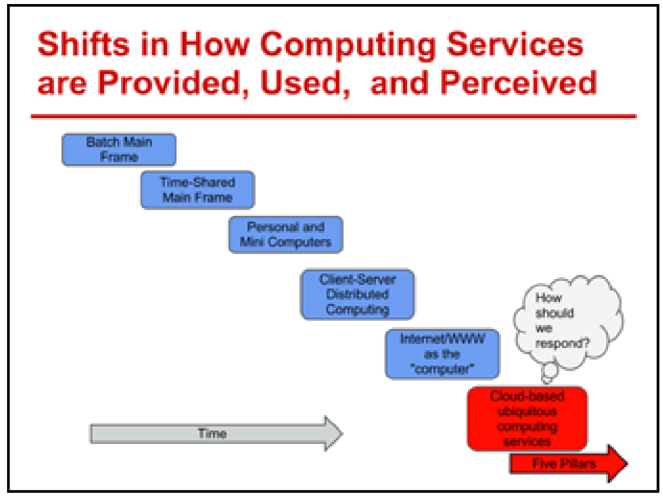
Third, it is important to recognize the ongoing struggle at NSF. We are in an era where the pendulum is demanding and incenting us to swing to more of a shared environment. Several decades ago we had time-sharing on a ten million dollar mainframe where by definition computation resources were shared. Then came the explosion of the mini-micro computing, where our computing assets were in our closet and then on our desktop. Now with clouds and big data it is coming back to shared infrastructure. So, what is the common stuff to be shared, and what legitimately needs to be customized to the needs on top of that? This is a big issue, related to the issue of trust. What do people need to have on their own? It is not just a matter of cost efficiency and reduction of redundancy, although this is very important. It is about building a platform that supports easily the interoperability between fields and institutions that we have all agreed are necessary to fuse together the resources and intellectual capital to make major progress. The point made in the Blue Ribbon Cyberinfrastructure Report mentioned earlier was that it was great that everyone was building collaboratories, since this was occurring just at the time where that interdisciplinarity research and education were increasingly important. They would run the risk of balkanization of these environments without a more coherent and collaborative approach.

We also need to stop thinking about the distinction among research computing environments, administrative computing environments, and earning computing environments. At least the research and education side should be thought of as a discovery and learning environment with a continuum between them.

And finally, we need to address at NSF and at other institutions not just the high peaks of "Big Science" but the long tail as well. There is incredible gain by building an environment that supports the long tail. We need to find the right level between shared and tailorability and that gives incentives for this Bromian Ring approach– an integrated, participatory, iterative design that brings it together.

We also need to think about endothermic vs. exothermic investments. Endothermic cyberinfrastructure is not sustainable at scale. Scale matters for the long tail as well. Lots of little things can be big. Part of this is how we talk about science policy and privatization. You can largely make cases on





technical merits. Once you start to talk about anything that begins with the letter "B", technical merit ceases to be primary criteria. We need to see what this contributes to national ways and means. Politics change at this scale. Lastly, we heard mention of the $500 M/y NSF cyberinfrastructure in a scale relative to $5 B/y federal investment recommended for the campuses. $500 million is roughly the cost of one cloud data center!

A question was raised concerning the suggestion that the computing environment for discovery could be a single computing environment. We have had people talk eloquently about how young people learn. There are mental models behind experiences in moments of need. The group also has discussed the accumulating knowledge about learning. There have been extensive discussions about discovery and the needs of big data, large science, and big corporations to conduct powerful, important science work. While Dan Atkin's vision has been that these things ought to be seamlessly connected, in fact they have been two separate discussions. It is possible a place like NSF could do something about the conjunction of those.

But this is also a supposition against the fundamental opposition between teaching & research in research universities. The plain fact is that most faculty members in these institutions are not interested in teaching if it gets in the way of their research. If you want real support for project and studio experiences, you must realize that such developments take time. They take interactions that are so time consuming that you don't have the time to publish papers and write proposals. If we do not find a way to enable the scaling studio and project experiences, we will not make those connections between cyberinfrastructure for research and be really engaged for authentic learning in K-9 and everyday learning of real people.

Hence the grand challenge: how to scale studio experiences not by the thousands, but even receiving 5 times the support to yield 5 times the project experience would be a fantastic change in one's ability to be an effective educator. To link that more productively to a faculty member's research would be a huge win. But unfortunately this is not on the radar screen of most institutions. We have only a few examples of people doing that effectively. The group's discussion has returned to the point that we have been in two conversations here that did not join. The discovery AND learning label captures that fact.

Another big challenge for educators is that our models of infrastructure are campus and location based. They have to be contained within the bundle of experiences on campus, making this a zero sum game. But the network has both capacity and extensibility. Even when looking at K-12, why aren't we leveraging the resources of the community? Why do we think that of job of education is loaded solely on teachers? Does the teacher have to know 3D modeling if kid wants to do such a thing? No. The most important thing with this conversation about shared resources and capacities is that these cannot be solved on an institution basis. We need infrastructural solutions about leveraging capacity of a broader network. If you have kids who are interested in a specialty, most are not well supported within a local community. But there is capacity – local colleges, hobby groups, corporations – if we think more broadly about what a public education looks like in a digital age. Today's conversation seems very tightly bound within institutional formal structures. Libraries, universities, K-12. What does a public media look like in the digital age? Wikipedia is one answer for public media. But perhaps we don't have the answer yet for public education.

Moore's Law

Although most characteristics of cyberinfrastructure, e.g., processing power, data storage, and network bandwidth, continue to increase at an exponential pace described by Moore's law, various components of the technology do eventually encounter limits and saturation that require major technology shifts. For example, VLSI processors and memories are approaching the limits of miniaturization and hence processing speed. In the near term, devices are exploiting multiprocessor architectures, with dozens of processors on a single chip (and millions of processors in supercomputers). But other constraints, such as power requirements, will soon require new technologies such as DNA storage and quantum computing.

Similar evolution continues to occur in how information is processed. For example, companies such as Google and Amazon are built around data, analyzing and extracting information and knowledge from large data centers (or clouds). Here, scale truly matters, with increases of factors of ten in storage and processing speed regularly required and achieved to meet market requirements. Similarly, data concepts have shifted to larger, more abstract structures such as entitles, concepts, and knowledge, that require enormous increases in data storage and processing speed. They also require more sophisticated software for data processing to enable rapid searches for abstract concepts through petabytes of data.

The Human Interface

One of the most rapidly changing characteristics of this technology involves the human interface. Although we look back at the transition from text to image to video to 3D immersive displays, there are other characters such as mobility, size, and context that also change rapidly. For example, the development of software agents that rely on natural interactions such as speech and context awareness are already transforming both mobile phones (e.g., Apple's Siri) and interfaces with the physical world (e.g., Google's efforts to insert computing into eyeglasses to assist in context analysis). The use of intelligent agents or assistants (IBM's Watson) can make us look better than we really are by anticipating and completing tasks that are not fully defined, although this raises an interesting set of policy and legal issues since even the most intelligent agents can make mistakes because of faulty information or incorrect assumptions based on inaccurate data. The question of what intelligent agents do on your behalf and liability issues are unresolved questions. Similarly, there is great interest in the evolution of the Internet into a network of objects such as ubiquitous sensors, the rise of contextual data, and the ability to do predictive models of individual behavior. The need for accessibility raises the issue of digital inclusion in the broadest sense. How does one design technology to assist physically challenged individuals, aging populations, those with limited literacy skills, and, indeed, provide a global population of 10 billion with robust digital access.

Although the rapid evolution of information and communications technology is driving much of the change in the activities of the university, it is important to consider this from a much broader perspective, including legal issues (patents, copyright), policy (local, national, international), and social issues (access and accessibility, equity, interoperability, sustainability, and resilience). For example, students and faculty need appropriate technology scaffolding for their academic pursuits (e.g., cyberinfrastructure). But they also need a broader understanding of systems thinking in addition to domain-specific knowledge, the future potential and disruptive nature of this technology, and the paradigm shifts in learning and discovery it is likely to drive.

The Next Big Paradigm Shift

So what are the early warning systems for the next major paradigm shifts? What does one look for? During the 1980s, a modest computer network, NSFnet, was developed to connect scientists to supercomputer centers, only to find that people did not want to use supercomputers but rather to communicate with one another. This led within a few years to the Internet, another technology that changed the world. Google spun out of the Page Rank search algorithm created by a Stanford research project to develop digital libraries. (Levy, 2011) Facebook was started even more modestly by a group of students seeking to digitize and distribute the picture book Harvard created for entering students. (Kirkpatrick, 2011).

So where do you look for these surprises? Do you look at the research labs on college campuses? Do you look at Harvard dormitories for what students are doing before they drop out? Do you try to spot the next Bill Gates, Mark Zuckerberg, or Larry Page? Do you have any tracking systems? Industry participants usually respond that they first sense such possibilities when activities characterized by hyper exponential growth break free of the campuses, e.g., the Internet, Google, and Facebook. Similarly, they look for interesting students and faculty members that they can break free of the campus culture. Their success model is based on what escapes rather than what stays inside academic institutions.

From industry's viewpoint, the elephant in the room is knowledge creation, not knowledge dissemination, which is the role of the research university. The challenge is to become more focused on knowledge creation, integration, synthesis, and dissemination, or perhaps more abstractly, DIKW: data, information, knowledge, and wisdom. One needs to use cyberinfrastructure together with tools that enhance creativity, and then broaden access through libraries, search tools, and push models in education.

As a framework, one can begin by observing that the fundamental activities of the university are organized into knowledge communities – those that engage with knowledge and discovery. (Brown, 2000) The extent to which the university facilitates knowledge communities should be the basis for its merit. Today, people can work together in four quadrants: same/different – time/place. One can build a rich connection between people, information, and tools. The work of these knowledge communities supported by a cyberinfrastructure platform can now be done in new workflows that go through space-time quadrants in different ways. Cyberinfrastructure now allows tools, data, experiments, and other assets to support online knowledge communities, making these functionally complete in any of the four quadrants, that is, with all the resources necessary to handle knowledge flow. Using the scaffolding of cyberinfrastructure, one can dramatically reduce constraints of distance and time. This creates a major disruption in how knowledge work is done, expanding significantly the degrees of freedom.

Change Is In the Air

The primary missions of the University, its teaching, research, and service activities (or alternatively, its activities of learning, discovery, and engagement with society) are increasingly dependent on, information and communications technology. The rapid advances in these technologies are not only reshaping but creating entirely new paradigms for research, education, and application not only in science and engineering but in all of the academic and professional disciplines. It has been clear for sometime that to maintain world-class academic programs, the University must also achieve leadership in the quality and relevance of the technology it provides at the level of each of its highly diverse teaching and research programs.

This is particularly challenging since the features of information technology such as processing speed, memory, and bandwidth, have been increasing in power at rates of 100 to 1,000 fold per decade since WWII. This is one of the major reasons for the continued surprises we get from the emergence of new applications–the Internet, social networks, big data, machine learning–appearing in unexpected ways at a hyper exponential pace. We have learned time and time again that it makes little sense to simply extrapolate the present into the future to predict or even understand the next "tech turn". These are not only highly disruptive technologies, but they are highly unpredictable. Ten years ago nobody would have imagined Google, Facebook, Twitter, etc., and today, nobody really can predict what will be a dominant technology even five years ahead, much less ten!

Just what purposes should drive IT strategy. To support the university mission? What mission? Of the University writ large? Of the academic units? Of generic language like teaching, research, and service…or discovery, learning, and engagement…or "Change the world!"…or what?

What should be the focus on solutions that are easily created and replaced? Agility to be sure. But what about resilience? And maturity? What about "optimum redundancy", so important to academic processes. For example, while Michigan formed a partnership with Google in 2012 at the enterprise level to Google, it soon learned that relations with companies with "startup" encountered difficulties in the support of "mission critical" applications such as university instruction. The University learned to be careful about becoming overly dependent on companies still embracing a "startup", e.g., high-risk, culture.

Who should the University regard as priorities for IT services? Students? Faculty? Staff? Administrators? New learning paradigms such as blended education; experiential, personalized learning. Actually, all of these activities have been part of the university's portfolio since the 19th century! Even the massive markets enabled by MOOCs is not really new. UM TV was teaching courses for credit with over 100,000 students through live TV in the early 1950s.

What is the appropriate strategy for enterprise-wide IT development? Most of the University's IT Strategic Plan is aimed at providing a cyberinfrastructure environment on campus. But the anyplace-anytime character of today's world leaves hanging the majority of the time spent working by our students, faculty, and staff, which is off campus in their homes, dorms, cars, wherever. Without a major plan for high-speed connectivity throughout the community, this is a very incomplete strategy. Most of the strategic investments associated with the NextGen infrastructure seem to be focused on-campus…WiFi networks, high capacity networks in data centers, labs, etc., use of clouds. But most of the time our people (faculty, students, staff) will be tethered to our resources through 4 MB/s cable or telcom carriers. Hence, without robust connectivity beyond the campus, these major investments will fall far short of our needs.

Where is the subject of institutional collaboration? Today our faculty work more with colleagues on the

products, particularly to the degree we constrain the cyber environments of academic units through policies such as purchasing and shared services, will harm the loosely coupled adaptive culture of the university that is one of our greatest strengths. This is particularly dangerous if we become overly dependent on particular vendors because of top-down rather than bottom-up forces. The reality is (and always has been) that it has been our faculty, staff, and students who spot the next big trends in technology and then drive change upward through the institution.

It is becoming increasingly clear that we are approaching an inflection point in the potential of rapidly evolving information and communications technology to transform how the scientific and engineering enterprise does knowledge work, the nature of the problems it undertakes, and the broadening of those able to participate in research activities.

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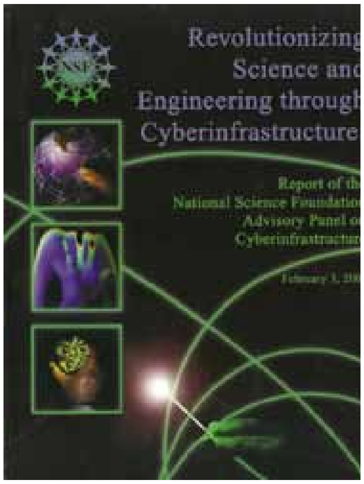
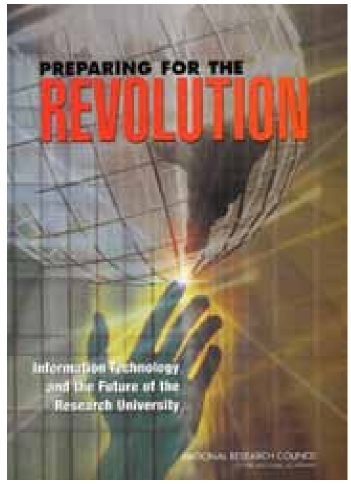
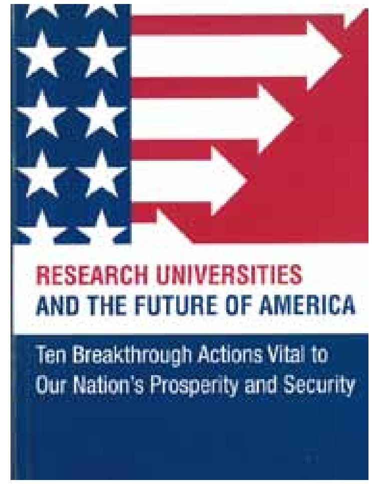
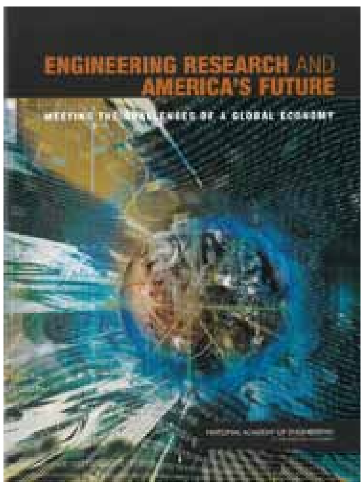
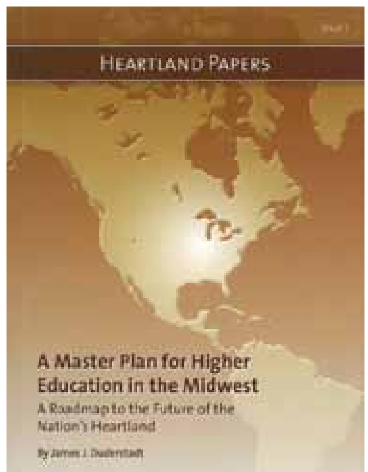
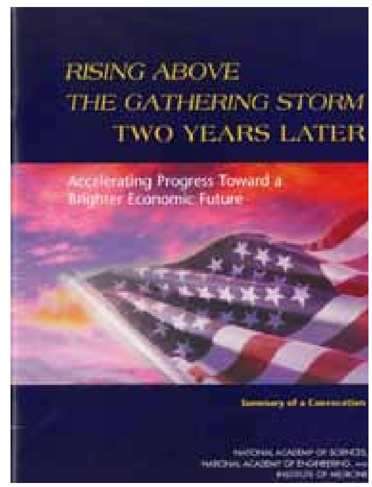


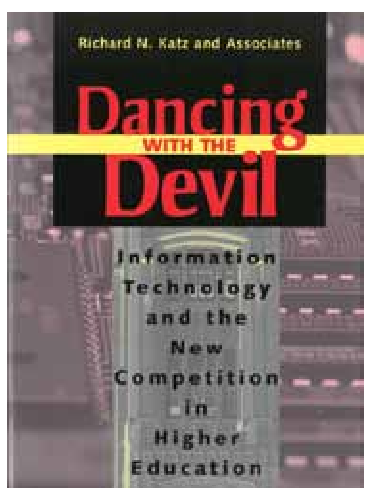


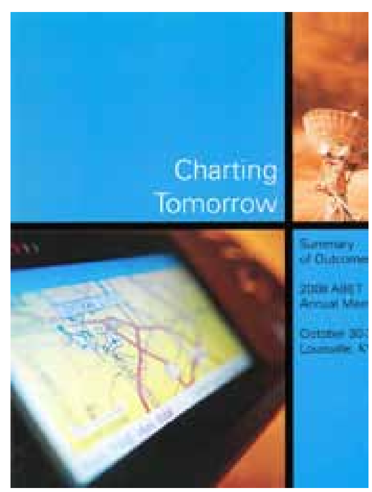












Many of the key reports from the National Academies and federal agencies such as NSF concerning the rising important of cyberinfrastructure for our world

Renaissance

Chapter 6

Books to Clouds

Just as the introduction of the printing press stimulated a Renaissance of creativity as the knowledge accumulated in books could be distributed throughout society through printing, the 1990 saw a similar creative surge in civilization through the digitization of books through efforts such as JSTOR, Google Books, and the HathiTrust. Except in this case, it was not simply the transfer of knowledge "from the library into the cloud", but the broader advances and integration of information technology to distribute not only knowledge but the tools of creativity to the world. It became increasingly clear that the evolution and application of digital technology was approaching an inflection point similar to the Renaissance of the Middle Ages when the tools provided by advances in knowledge were becoming available to ever expanding communities.

As suggested by Dan Atkins, it was time to replace the term "digital age" by "the connected age". While the underlying technology of this age is certainly digital in nature, the real opportunity is in its extreme connectedness: people to people, to information, to instruments, to facilities, to arrays of computational tools. While the transformation described in the previous chapter involved the technology for social media and building organizations such as Google, Facebook, and Amazon, this was only one element of an increasing powerful environment, including advanced computation, simulation, data mining, virtual reality, and even artificial intelligence.

MIT's Open CourseWare Initiative

During the 1990s the MIT faculty made the bold decision to put the digital assets supporting all 2,000 of their courses into the public domain, enabling their use by students, faculty, and universities throughout the world in a well-organized, searchable manner. (MIT President Charles Vest called the night before the announcement to ask if we thought this was crazy...)

The user community of what MIT called the Open CourseWare initiative grew rapidly to over 3 million people around the world–and, of course, eventually all MIT students. Over 100 universities embraced the OCW paradigm to distribute their own instructional materials, including the British Open University.

Closely related was the Sakai project based at Michigan and consisting of a consortium of several universities (Michigan, MIT, Indiana, Stanford, Oxford) and corporations (IBM, Apple, Cisco, and Unisys) to develop open-source middleware to support the teaching and research activities of higher education. Several hundred colleges and universities moved to the Sakai platform and CTool course management system, including the full range of instructional activities at Michigan during the early 1990s (and later in the 2000s to new systems such as Canvas).

Beyond the support of classroom instruction and scholarly activities, the Sakai team and their collaborators explored taking elements of their open source middleware up to the enterprise level (for administrative purposes) and down to the desktop level (within the Linux framework). They also were involved in a large effort to develop technology to support the Open CourseWare effort pioneered by MIT.

Digitizing Books into the Cloud

The University of Michigan launched another major technology contribution during the 1990s when its faculty and staff began to explore the creation of digital libraries. In a sense the library would become the early poster child for the impact of IT on higher education.

MIT OpenCourseWare

Other Open Content Initiatives

Beyond the use of digital technology for organizing, cataloguing, and distributing library holdings, the increasing availability of digitally-created materials and the massive digitization of existing holdings (e.g, the Google project to digitize and put online in searchable format the entire holdings of major research libraries) is driving massive change in the library strategies of universities.

The JSTOR Project

Proposed by William G. Bowen, former president of Princeton University, and led by Randy Frank and Dan Atkins, the University launched the first major effort to digitize a massive collection of journals by building the JSTOR library of the Mellon Foundation for digital archiving and providing access to scholarly work in history and economics. This was later expanded into a major NSF project to build a digital library.

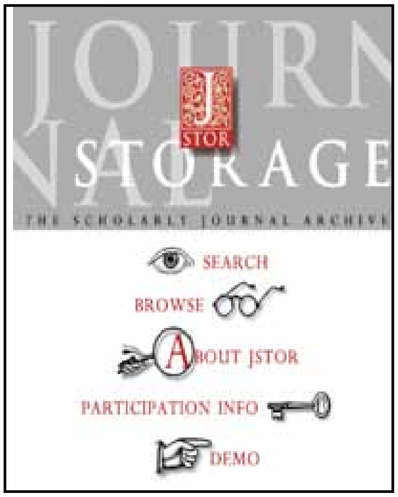
The goal was to create digital libraries to provide intellectual access to collections of information by creating environments, which beyond providing access to raw data–the "bits"–containing the fuller knowledge and meaning contained in digital collections. Since more and more information was born digital, and electronic access was increasing at a rapid pace through global network connectivity and higher bandwidth, new information management tools, and importantly, interoperability across systems and information content was essential.

The Michigan Digital Library Initiative used agent-based technology to enhance the fit between user and the level of information they needed. It was applied in science classes in the Detroit Public Schools and in Native American Tribal Colleges. But perhaps most important , it created capacity at Michigan to enable prototyping the JSTOR online journal system sponsored by the Mellon Foundation, which eventually contained 2,000 journals and was used in 160 countries. JSTOR operated as an independent-self-sustaining nonprofit organization with offices in New York City and Ann Arbor, Michigan until 2003, when it merged with the nonprofit Ithaka Harbors, Inc., an organization dedicated to broader studies of how advancing information and network technologies could impact academic activities.

The Google Book Project

One of the Michigan computer science students at that time was, Larry Page, who continued on to graduate school at Stanford (also part of the NSF digital library project), where he and Serge Brin developed the Page-Rank algorithm that was the key to the Google search engine.

In 2004 he returned to Michigan and offered to have Google digitize Michigan's entire library (all 8 million volumes), which would become the nucleus of a major book search service by Google. Of course it was hard to imagine a university doing this on its own because of cost. But Michigan responded positively to Google's offer, and it agreed to digitize its entire collection with



Jstor

Google Books

Google's assistance. Michigan's earlier involvement in JSTOR digitization project, sponsored by the Mellon Foundation, also gave it a good head start on this project.

What drove the UM's decision to let Google digitize 7.8 million volumes in its collection? As its provost Paul Courant stressed "Our purpose is to extend the realm of ideas in the broad service of society."

Michigan received its own copy of this digitized material for use in its scholarly and educational programs. Google committed to provide searches through these materials, with appropriate safeguards to protect copyrighted materials. This activity was underway, with digitized materials from Michigan coming online in 2004 through Google Book Search and downloads of public domain materials then available both through Google and MBooks.

Google moved ahead to also digitize the the library collections of Stanford, Harvard, Oxford, and the New York Public Library. Later the G5 became G7 with the addition of the Universities of California, Wisconsin, and Madrid.

It was estimated that as of January 2005, approximately one month after the Google announcement, WorldCat contained about 32 million records describing print books, or slightly less than 60 percent of the entire database. It was clear that print books accounted for a significant proportion of library collections, at least to the extent that these collections are reflected in WorldCat.

The proportion of the system-wide collection actually covered by the Google digital library, once duplicate holdings across the five institutions were removed, was about one third (33 percent), or 10.5 million unique books out of the 32 million in the system-wide collection.

The HathiTrust

While Google was successful in completing this massive digitization project, the company soon realized that they had no way to use it to make a profit. Hence Google returned to Michigan and offered the University the complete collection if this would used as the core of a digital library comprised of many of the nation's leading universities.

Led by provost Paul Courant and UM Librarian John Price Wilkins, Michigan went beyond the original participants in the Google Book project to lead a group of universities and libraries (80 thus far) in pooling their digital collections. They created an even larger digital library, the HathiTrust ("Hathi" means "elephant" in Hindu), adding over 400,000 books a month to form the nucleus (today at 18 million books, with 8 million of these already open for full online access). While many copyright issues still needed to be addressed, it was likely that these massive digitization efforts would be able to provide full text access to a significant fraction of the world's written materials to scholars and students throughout the world within a decade. Michigan had played an important role in opening up access to both scholarly publications and digital archives critical to the


Paul Courant


John Price Wilkins

advancement of knowledge in an increasingly digital world.

What Has the Library Become in the Digital Age

While most universities were continuing to build libraries, many were no longer planning them as repositories (since books were increasingly placed in off-campus retrievable high-density storage facilities) but rather as a knowledge commons where users accessed digital knowledge on remote servers.

When pressed, it turned out that the most common characteristic of these new libraries was a coffee shop. They were being designed as a community center where students came to study and learn together, but where books were largely absent. The library was becoming a people place, providing the tools to support learning and scholarship and the environment for social interaction.

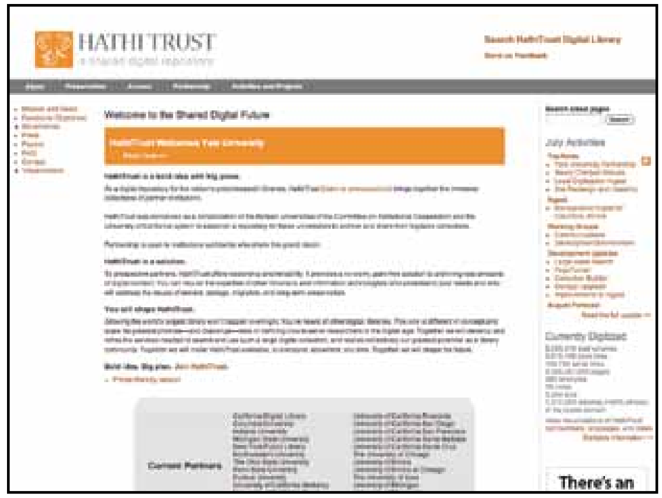
Yet the participants in workshops also raised the very serious issue concerning the preservation of digital knowledge, now increasing at a rate an order of magnitude faster than written materials. Without a more concerted effort for the standardization of curation, archiving, and preservation of digital materials, we may be creating a hole in our intellectual history. Traditionally this has been a major role of the research university through its libraries. There was a general agreement that research universities needed to collaborate more on their responsibilities for the stewardship of knowledge in the digital agenda the realm of ideas in the broad service of society."

In a NYT article in 2007, Kevin Kelly recalled an age old dream of having in one place all knowledge, past and present, all books, all documents, all conceptual works, in all languages. He noted that the closest we ever came was the Great Library at Alexandria, constructed about 300 BC, which once held between 30% and 70% of all books then in existence. Yet this dream was quickly overwhelmed by the explosion of civilization and knowledge throughout the world and became an impossibility...

"Until now, when Google announced in December 2004 that it would digitally scan the books of five major research libraries to make their contents searchable, the promise of a universal library was resurrected. Indeed, the explosive rise of the Web, going from nothing to everything in one decade, has encouraged us to believed in the impossible again. Might the long-heralded great library of all knowledge really be within our grasp. We can provide all the works of humankind to all the people of the world. It will be an achievement remembered for all time, like putting a man on the moon. And unlike the libraries of old, which were restricted to the elite, this library would be truly democratic, offering every book to every person."

So what is the university library in the digital age? Is it built around stacks or Starbucks? Is it a repository of knowledge or a "student union" for learning? In fact, perhaps this discussion was not really about libraries at all, but rather the types of physical spaces universities require for learning communities. Just as today

Library of Alexandria



Hathi Trust

every library has a Starbucks, perhaps with massive digitization and distribution of library holdings, soon every Starbucks will have a library–indeed, access to the holdings of the world's libraries through wireless connectivity.

In a sense, the library may be the most important observation post for studying how students really learn. If the core competency of the university is the capacity to build collaborative spaces, both real and intellectual, then the changing nature of the library may be a paradigm for the changing nature of the university itself.

Yet, as John Price Wilkins stresses, the power of the HathiTrust continues to evolve. It is only the second repository (after Portico) to receive certification. A second grand accomplishment has been the creation of a viable full-text search mechanism that works with all of the content in the repository. This effort required a large amount of research and testing since we learned required deep collaboration with the broader community of developers. The resulting service is sensitive to the amount of content—unparalleled in size—to the hundreds of languages and character sets, and to requirements like phrase searching that reflect the distinctive ways users approach a vast and diverse library collection. The HathiTrust users can now search over 3 billion words and get results in a split second. The functionality that we have today is tremendous, and it provides a foundation for a next generation of search that gives our users access to bibliographic information where needed, and full text where desired (Wilkins, 2017).

The School of Information

The success of the digital library, when coupled with the vast reach of the Internet, suggested that long-standing educational structures such as schoools of library science would drastically change. At Michigan, the School of Information was very much a grass-roots effort, flowing up from the interests and creativity of the faculty and building upon the efforts of a number of people over a considerable period of time. During the 1980s, Robert Warner, University Librarian and Dean of the School of Library Science had been making the case that there was a real opportunity to create something quite extraordinary by investing in the School of Library Science.

As it happened, Dan Atkins and Jim Duderstadt had been in discussion for sometime about the possibility of creating within the University a "skunkworks" operation to explore the implications of rapidly evolving information technology for the knowledge functions of the university. Here this would be an analog to the Lockheed Skunkworks, founded by a Michigan aeronautical engineer Kelly Johnson, that used a very innovative form of team-based R&D, usually under great secrecy, to develop some of the most dramatic breakthroughs in aircraft technology. Every few years the hanger doors would open, and something quite weird and unexpected would be rolled out…the U-2 spy-plane.…

SOI Founding Dean Dan Atkins

Early Planning: Dan Atkins, Gary Olson, John King, and John Seely Brown

Key faculty: Gary Olson, Judy Olson, John Price Wilkins, and Lynn Conway

Dan Atkins had characteristics very similar to those of Kelly Johnson, in his capacity to lead a small group of folks to accomplish quite extraordinary things. He had led the effort to create a world-class computing environment in the College of Engineering's Computer Aided Engineering Network. He was working closely with NSF on IT-based projects such as collaboratories and electronic documents. Hence from the outset it was clear that he would be the ideal leader of such a skunkworks effort. Yet there was a problem here since we were well aware that novel ideas hatched within the confines of the central administration typically bounced off a University culture strongly driven by academic units without making a dent.

Hence, Warner's efforts to attract our attention to the School of Library Science triggered one of those light bulb ideas: Why don't we make Library Science our skunkworks for exploring the new paradigms for knowledge technologies? After all, librarians had mastered the task of collecting, curating, and distributing knowledge throughout human history, from the days of the Library of Alexandria and already possessed some formidable capabilities. Furthermore, as a very small unit, the resources required for transformation would not be excessive.

And, it should also be acknowledged that using the School of Library Science as our research laboratory for digital archiving really would not threaten anyone at the outset. The efforts of School had been seriously

The School of Information in North Quad

threatened by budget cuts during the early 1980s, with significant losses of faculty and funding. In fact, there even been discussion of program discontinuance. Hence little resistance was anticipated to an entirely new character of a school concerning the impact of computer technology on knowledge.

Little was it realized that not only would a School of Library Science be transformed into a new School of Information, but with the digitization of books into the cloud, the university would be augmenting librarians with a new profession training a new profession, *informationists*, experts on searching cyberspace for information.

The School of Library Science became the new School of Information, with Dan Atkins as its first dean. Several of the University's information technology leaders were given appointments in the School, including Gary and Judy Olson, Lynn Conway, Michael Cohen, John Holland, and Doug vVn Houweliing.

Beyond the willingness of the UM President to provide whatever funding Atkins requested for the new school, major national agendas stimulated even more rapid growth. Key here were major book digitization projects such as the Mellon Foundation's JSTOR project and the NSF's EXPRES project to develop computer-based methods for proposal submission and evaluation. Dan Atkins developed close relationships with the Kellogg Foundation, which became a major sponsor of many of the School's activities amounting to over $20 million.

The UM School of Information became the prototype for the development of many other SI schools, including Berkeley (with Hal Varian and Jeff Mackie-Mason from Michigan). It also provided the foundation for the massive digitization of libraries ("putting books into the cloud") that would characterize the Michigan's later leadership with the HathiTrust.

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Chapter 7

The Renaissance Campus

The University of Michigan provides an interesting example of how academic programs characterized by technology-driven creative activities can evolve. On the University's North Campus, the University is fortunate to have several schools–music, dance, and the performing arts; art and design; architecture; engineering, and information–that focus on the creative activities that increasingly require new tools. In fact, the deans of these schools frequently referred to the North Campus as the "Renaissance Campus". (The North Campus coffee shop in the Pierpont Commons was named "Leonardo's".)

Key in responding to the unusual creative nature of these schools was a new facility proposed by the deans to serve as a "creative commons" supporting interdisciplinary activities in "making things"–3-D objects, virtual reality simulations, new art forms, CGI-based performances, responding to a growing need for both student learning and faculty participation in such activities. Initially named the "Media Union", the new facility was envisioned as an innovation commons or creation space where students, faculty, and staff from multiple disciplines could gather to create, invent, design, and even make things (whether objects of art, performances, buildings, or new technologies).

The fundamental purpose of the Media Union was to provide the North Campus schools with access to the rapidly evolving technologies that would change both their disciplines and their educational paradigms. Although all of the schools were exploring the impact of computer technology, the Internet was still relatively new, and the transition of documents from physical books to digital libraries (and into the "cloud") was just beginning. It was also intended as an innovation commons, where students from the various North Campus disciplines (along with those from Central Campus venturing into the "north country") could join together to learn and create.

The University of Michigan Media Union

The team of deans, faculty, and staff responsible for the design of the new project envisioned it as more akin to the MIT Media Lab, although extending its mission beyond research to include instruction and performance. It was designed as a high-tech collection of studios, laboratories, workshops, performance venues and gathering and study spaces for students. The Media Union was viewed from the beginning as a place intended primarily for collaboration and innovative learning, research, and performance, a place where students, faculty, and staff could access a technology-rich environment to create their dreams, a place open to all "who dared to invent the future".

As explained by John Merlin Williams, the Director of the Duderstadt Center during much of its history, its mission was also to provide students and faculty with access to advanced tools and the experience of collaborative, interdisciplinary practice to prepare them for their future careers. Students need to use the "real stuff" of their professions and be guided by real-life practitioners to be a success in their fields. Hence the Center was designed to offer a distinctive combination of advanced network and computational technologies, specialized software, technically rich spaces, professional practioners, and collaborate work environments free of intellectual and physical barriers to interdisciplinary discovery. It was not a space filled simply with learning technologies but rather the advanced tools students needed to master for professional success. It provides the scaffolding for technology intensive work–the facilities, infrastructure,

School of Music, Theatre, and Dance

College of Engineering

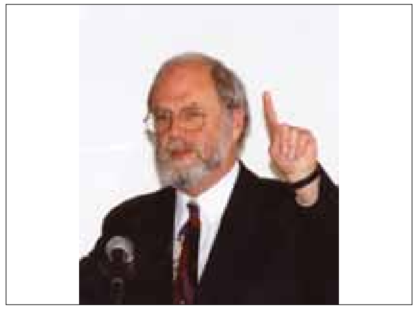
School of Architecture and Urban Planning

School of Art and Design

School of Information (before move to NC)

Walgreen Center

Paul Boylan



Robert Beckley

Allen Samuels

Peter Banks

Dan Atkins

Randy Frank

Lynn Conway

Maurita Holland

Judy Olsen

The "Dream Team" of North Campus deans and faculty who created the concept for the Media Union

and the staff–so that students and faculty can move rapidly to the creative level of their projects with a small faction of the effort usually required.

These discussions began to converge on the concept of a major facility, a "commons" for the students and faculty of the North Campus programs, that would provide the new technologies not simply for their traditional instructional and research programs, but that would kindle new innovative and creative projects. Since this would require major new facilities, as President, Jim Duderstadt was drawn into the discussions since one of his roles was "begging for dollars" to support both the ongoing needs and the exciting new ventures proposed by academic programs.

The concept of an "innovation-creativity center" based on state-of-the-art communications and information technology supported by leading professional staff soon was translated into a goal for $45 million of state support. In lobbying for state support, they used the name "Integrated Technology Instruction Center", in the hopes that this would create support from the Governor and Legislature. Although was successful in stimulating funding, it meant nothing and was later changed by the deans into "Media Union".

The Evolution of the Media Union

Over the first two decades this facility "full of unknowns" became the home for a large and evolving


The North Campus Deans breaking ground for the new ITIC complex


Project Manager Randy Frank leading a tour of the construction site.


Jim and Anne Duderstadt and Doug Van Houweling join Governor John Engler in dedicating the ITIC complex.

The original design by Architect Albert Kahn and Associates

The Duderstadt Center

Anne and James Duderstadt

collection of new information and communications technologies far beyond the resources that any one school or college could acquire and maintain. The Media Union's collection of digital assets and resources required constant renewal with the latest versions of software and hardware, and an expert team of professionals who enable U-M users to get up-to-speed and use them productively for innovative research and teaching.

The Media Union rapidly became one of the most active learning spaces in the University, providing thousands of students with 7x24 hour access to rich resources including libraries, advanced technology, workshops, performance venues, and high quality study and community gathering spaces. It evolved into an innovative center for discovery, learning, invention, innovation, demonstration, and deployment utilizing state-of-the-art technologies and facilities and assisted by expert staff. Today it serves as a new form of public good, an innovation commons, where students and faculty would come to work together with expert staff mentors to develop the skills and tacit learning acquired through studios, workshops, performance venues, and advanced facilities such as simulation and immersive environments. The Media Union encourages experimentation, tinkering, invention, and even play as critical elements of innovation and creative design.

Rationalizing significant investments in cutting-edge resources by enabling free access to a shared, expertly supported collection of assets has enabled a widespread culture of innovation in digital technologies at the U-M. Students and faculty are free both to envision and to lead, hands-on, change in disciplines being transformed by the digital revolution – from engineering, the performing and design arts, and medicine, to economics and government.

The Duderstadt Center

In 2004, in keeping with a long-standing tradition of naming an appropriate building after each former president, the Media Union was renamed the James and Anne Duderstadt Center, or more commonly known to students simply as "the Dude". This also recognized the effort that President Duderstadt and his team put into convincing the State of Michigan that they should provide $45 million to create this new technology-based center of learning, discovery, and creativity.

Perhaps one student best captured the role of the center when asked to explain its purpose as: "The Dude is the place you go to make your dreams come true!"

Today, the Duderstadt Center has become one of the most active learning spaces in the University, providing thousands of students with 7x24 hour access to rich resources including advanced technology, workshops, performance venues, and high quality study and community gathering spaces. More specifically, beyond its current role as a gathering space for learning and research, the Duderstadt Center has become an innovative center for discovery, learning, invention, innovation, demonstration, and deployment utilizing state-of-the-art technologies and facilities and assisted by expert staff. It provides the resources to support a community engaged in the creative transition from concept to technical realization. In fact, today the Duderstadt Center has evolved still further into a generalization of the university itself, using technology to add to the traditional university activities of teaching, research, and service, deeper intellectual activities such as creativity, innovation, demonstration (e.g., performance), and impact on society.

The Center serves as a new form of public good, an innovation-creativity commons, where students and faculty come to work together with expert staff mentors to develop the skills and tacit learning acquired through studios, workshops, performance venues, and advanced facilities such as simulation and immersive environments. The Center strongly encourages experimentation, tinkering, invention, and even play as critical elements of innovation and creative design. It invites and enables the creation of highly interdisciplinary teams of students and faculty from various academic and professional disciplines, providing a Greek agora, where people can come to network, exchange knowledge, and create new ideas with experienced staff.

Beyond providing a technology-intensive platform for learning, discovery, creation, and innovation, it has also become a place for studying new paradigms for these activities and propagating them to the rest of the University. In this sense it serves as a "skunkworks" for the future of learning and discovery, a "do tank" rather than a "thinktank", where new paradigms can be created, explored, and launched to serve society. As such, the DC is reaffirming its original vision, as first proposed by the North Campus deans, of serving as a change agent exploring new visions for the future of the university as a public good that provides rich resources that enable students and faculty "to know" (inquiry, discovery, learning), "to do" (skills, experience, mentors, tacit knowledge), "to become" (team building, communities of practice), "to create " (workshops, studios, tinkering, intuition, invention, innovation), and "to spinoff" (intellectual property, entrepreneurship, economic impact).

Elements of Today's Duderstadt Center

Design Labs: The DMC's Design Labs are creative learning environments that support initiatives to bridge disciplines, build networks and discover new contexts for scholarship. The most important resource you'll find here are the student content experts: the consultants who lead learning and research activities. Looking for hard-to-find expertise, or a collaborator?

Conference Rooms: The Duderstadt Center has four conference rooms available for meetings, workshops, etc. These rooms are available to U-M groups for academic and student service purposes (for social events, we recommend the Pierpont Commons). To maximize access, these rooms may not be scheduled for regular classes or weekly meetings. A class requiring video conferencing may schedule a conference room for those particular class sessions.

Gallery: The major function of the Gallery is to exhibit the widest range of creative talents from within the University. The exhibits can be either two- or three-dimensional, from art to engineering products, or computer-based interactive displays. Artifacts can be free standing, placed on pedestals (which we provide), or hung on the walls and from the unistrut ceiling structure. The space consists of a 2600-square-foot octagonal room fronted by a long glass wall. The wall can be opened for receptions. The glass doors from the Connector Hall to the outside also open, providing outside access for large structures and allowing for open-air receptions — weather permitting.

GroundWorks: A walk-in, self-serve media lab with hardware and software for creating, editing and converting audio and video recordings. It is open any time the Duderstadt Building is open. The lab features:

- Mac and PC workstations
- DVD recorders
- CD/DVD duplicators
- Document scanners
- Video dubbing equipment
- Software for audio, video, 3D, graphic design, programming, and more...
- Lynda.com video tutorial access

- Recording booth
- Multimedia workrooms
- Large format poster printing

Multimedia Rooms: There are three high-powered, reservable Multimedia Editing Rooms.. Beyond providing a quiet environment for working, the rooms have a number of extra features, including Mac Pros with substantial RAM and processing power, high fidelity audio monitors, two HD displays, a 4K reference monitor, Blu-Ray burners, music keyboards and computer keyboards labeled with Final Cut Pro shortcuts for easier editing. The Multimedia Editing Rooms are ideal for a big project that requires quiet concentration, or for small groups that want to work together without disturbing others.

Personal Studios: The Personal Studios are designed for users to create dynamic video ready for publication at the push of a button. This all in one, easy to use video production resource provides preconfigured professional lighting, teleprompter, backdrops, cameras and microphones. Users operate the versatile Wirecast software to switch shots, add titles, picture in picture, realtime greenscreen keying, multiple cameras, annotation capability and a laptop connection with modes for capturing or streaming an activity. Orientations daily, class orientations by request.

Audio Studio: The Audio Studio is an audio laboratory set up in the style of a recording studio. The resources are intended to encourage experimentation and research, and develop skills and techniques in audio production. The studio consists of five rooms: the control room, main tracking room, two isolation booths, and an amp room. It has been set up with the resources to explore stereo recording, surround recording and surround recording with height.

Study Rooms: Eighteen study rooms are located on the second floor and one group study room is located on the lower level of the Duderstadt Center for individual or small group study. Sixteen of the 19 rooms can accommodate one or two people, and three are intended for groups of 3 or more. Seventeen of these individual study rooms may be reserved in advance and two additional individual study rooms are available on a walk-in basis.

Training Rooms: The DMC has two computer training labs that are open to all U-M students, faculty and staff — though reservations are required.

Video Studio: The DMC Video Studio is an experimental media lab and high quality documentation space that is available to the entire University of Michigan's community. Well equipped and staffed, it enables original concepts and ideas to be turned into rich media that can be shared with the world. The Video Studio is also a collaborative sandbox, where faculty, students, visiting educators, scientists and artists come to collaborate and to produce or display high quality video and audio and to experiment with media technology. Whether it be capturing green screen sequences, recording motion capture data, experimenting with projection mapping, or documenting an original performance using multiple cameras and microphones - to name just a fraction of the possibilities - Video Studio projects are typically experimental or academic and represent learning, teaching and research across the disciplines.

Visualization Labs: 3D Lab, Visualization Hubs, MiDen, StereoWall

Computer and Video Game Archive: The Computer and Video Game Archive in the lower level (basement) of the Art, Architecture and Engineering Library collects materials relating to games for the purpose of academic inquiry, including but not limited to:

- Programming and technology
- Artistic and literary expression
- Social and cultural impact
- Instruction and education

Visitors to the archive can play a wide variety of games from the 1970s to the present. The archive does not allow games to be loaned out; it is instead equipped with a complete collection of consoles and related equipment for visitors to use.

Further Evolution of the Duderstadt Center

How should the Duderstadt Center evolve in the years to come? There are many options:

- A technology-intensive community learning and gathering space for the University
- A primary University resource (technology, internet, clouds)…"to know"
- A place for learning "to do", developing skills, tinkering, invention tacit knowledge studios, labs, workshops, performance venues
- A place for learning "to be", becoming a professional team projects, practice and performance venues, communities of practice and performance, immersive simulation, games and play
- A creativity and innovation commons where students and faculty come to create, "to make their dreams come true"
- A center for translational applications, "to propagate" into society not just new ideas but actual creations
- A "media union", interdisciplinary, merging of the media
- A skunkworks, a "do tank" (in contrast to the Central Campus "thinktanks")
- A center for advanced technologies (artificial intelligence, virtual reality, big data analytics, …)

More broadly, how should the University of Michigan itself face the digital age? Over the past four decades, computation speeds have increased a billion-fold. In fact, most characteristics of this technology are continuing to evolve exponentially at rates of 100 to 1,000-fold per decade. This is one of the big reasons for the continued surprises we get from the emergence of new applications–the Internet, social networks, big data, machine learning–appearing in unexpected ways at an ever faster pace. We have learned time and time again that it makes little sense to simply extrapolate the present into the future to predict or even understand the next "tech turn". These are not only highly disruptive technologies, but they are highly unpredictable. Ten years ago nobody would have imagined Google, Facebook, Twitter, etc…and today, nobody really can predict what will be a dominant technology even five years ahead, much less ten!

Fortunately, the University of Michigan has been able to respond to such rapid technological change in the past–and, indeed, achieved leadership–because it has functioned as a loosely coupled adaptive system with many of our academic units given not only the freedom, but also the encouragement, to experiment and to try new things.

At an NSF sponsored conference at Michigan on the role of cyberinfrastructure in discovery and learning, many participants stressed the importance of "craft", of the contributions of truly talented staff who drive innovation in units where they are most competent. The list of such people at Michigan is very long, e.g., people like Eric Aupperle, Randy Frank, Joseph Hardin, Paul Killey, and many, many others. These people are attracted to Michigan to work in academic units with faculty and students where they are highly valued and have the freedom to do exciting work.

The current pervasive digital revolution and cyberinfrastructure has enabled radical transformation of technological, economic and social environments. The digital revolution has removed so many of the constraints that today hundreds of millions of individuals, with modest investment, can turn almost any content into a public artifact accessible by billions of people at any time, in any place, on a wide range of devices.

This suggests a new social contract: to be intentional about engaging all disciplines that affect and will be affected by the cyberinfrastructure revolution and to create alignments that can help anticipate and begin to create practices and policies that maximize legal, social and economic freedom. It transforms the learning experience into the constructionist models of John Dewey and Seymour Pappert.

Extending the design principle of the Duderstadt Center should lead us to avoid placing obstacles in the path of the unexpected, what "could be," just as much as we plan resources to anticipate what is "likely to be." Planning for the likely, while removing the obstacles to that which could be, is a simple interpretation of what designers are calling modeless environments.

And most important of all, it enables the University to continue to attract, support, and value the outstanding technical staff that are not only key to building and maintaining the sophisticated technologies key to the mission of the Duderstadt Center, but also serve to teach students and faculty how to use these powerful resources.

A Future Shaped by Creativity

We are creating an environment where students and faculty can dream and then act on their dreams.

—Paul Boylan of the Dean, School of Music

A determining characteristic of the university of the 21st Century may be a shift in intellectual focus, from the preservation or transmission of knowledge, to the process of creation itself. Here, the University of Michigan is already very well positioned. On our campus, we already are fortunate to have several schools that focus on the act of creation, in music, dance, and the performing arts; art and design; architecture; and in engineering—which, of course, is the profession concerned with "creating what has not been." But, the tools of creation are expanding rapidly in both scope and power. Today, we have the capacity to literally create objects atom-by-atom. We are developing the capacity to create new life-forms through the tools of molecular biology and genetic engineering. And, we are now creating new intellectual "life forms" through artificial intelligence and virtual reality.

Even libraries will increasingly become places where the difference between "researching" and "doing" blurs. As Dan Atkins points out, the new information technology not only supports information retrieval, but also helps scholars actually manipulate that information. He notes that today a student can not only read about architecture, but use a computer tool at the same time to try out a design. The University will need to structure itself in a more strategic fashion to nurture and teach the art and skill of creation. Alliances with other groups, organizations, or institutions in our society whose activities are characterized by great creativity would dramatically enhance our capacity to move in this direction.

Yet here the contributions of an innovation and creativity commons merging the creative arts and disciplines on a university campus may play even a more significant role. Our world is changing rapidly, driven by the role played by educated people, new knowledge, innovation, and entrepreneurial skill. While these forces challenge us and our social institutions, they also contain the elements of what could become a *renaissance* of creativity and innovation in the 21st century. Since universities will play a critical role as the source of these assets of the age of knowledge, our vision for the early 21st century involves stressing similar characteristics among our people and our programs, e.g., creativity, innovation, ingenuity, invention, and entrepreneurial zeal. Put another way, the future university must add to its traditional motto of *lux et veritas*, the scholarship to discover *truth* and the learning to *enlighten* society, the mission of *genius* itself, of the creativity demanded by an ever changing world.

Of course while learning and scholarship have long been viewed as missions of the university, so too has been the creation of new knowledge across all intellectual and professional disciplines. Developing new approaches to scholarship, great works in literature and the arts, ingenious approaches to investigating physical and social phenomenon, these have long been the goal of most scholars. Not just to preserve and transmit knowledge, but to actually create it.

The professions that have dominated the late 20th Century—and to some degree, the late 20th Century university—have been those that manipulate and rearrange knowledge and wealth rather than create it, professions such as law, business, accounting, and politics. Yet it is becoming increasingly clear that the driving intellectual activity of the 21st Century will be the act of creation itself, as suggested by Jacques Attali in his provocative forecasts for the 21st century at the turn of the Millennium:

"The winners of this new era will be creators, and it is to them that power and wealth will flow. The need to shape, to invent, and to create will blur the border between production and consumption. Creation will not be a form of consumption anymore, but will become work itself, work that will be rewarded handsomely. The creator who turns dreams into reality will be considered as workers who deserve prestige and society's gratitude and remuneration."

(Jacques Attali, 2000)

But today new tools of creativity are appearing that are characterized by extraordinary power. We have the capacity to create new objects literally atom by atom. With new methods in molecular biology such as CRISPR/Cas9 and gene drive, we can not only precisely modify the DNA code for a living organism, but actually cause it to propagate through a species to change future generations (a frightening thought when human gene editing is considered). The dramatic pace of the evolution of information technology shows no sign of slowing, continuing to advance in power from 100 to 1000-fold a decade, enabling not only new forms of analysis such as augmenting the traditional tools of experiment and theory with the sophisticated tools of data analysis (big data). Indeed, the tools of artificial intelligence not only are rapidly progressing but have stimulated fears of eventual sentient behavior of machines. These tools also have changed the opportunities available in literature, performance, and art, with powerful tools of investigation and display (e.g., the CGI techniques increasingly dominating the film industry.)

Already we are seeing the spontaneous emergence of new forms of creative activities, e.g., the "maker" fairs providing opportunities to showcase forms of artistic, recreational, and commercial activity; the use of "additive manufacturing" to build new products and processes atomic layer by atomic layer; and the growing use of the "app" culture to empower an immense marketplace of small software development companies. In fact, some suggest that our civilization may experience a renaissance-like awakening of creative activities in the 21st century similar to that occurring in 16th century Europe.

Of course, the creative process of design has long been the culmination of the engineering process, the ultimate application of science and technology to meet the needs of society. As such, engineering design is an intellectual endeavor very similar to that encountered in the creative arts, but distinguished by its rigor and use of scientific and technological tools. Unlike research, which attempts to induce general conclusions from specific experiences, engineering design is a rigorous deductive process that develops a specific solution to meet a specific need from a general set of principles. Engineering design is a far more general, powerful, and disciplined approach than mere invention. In addition to innovation, ingenuity, and creativity, design requires great skill and training. It is not an activity left to happenstance, to accidental discovery. Rather, engineering design is approached with the disciplined methodology of engineering problem solving.

Ironically, the immense importance of design in addressing the myriad needs of a rapidly changing world has not received the visibility and priority of other activities such as "creativity", "innovation, and "entrepreneurship" that are clearly dependent upon it. So, what to do to provide this rigorous intellectual skill, so critical to innovation, entrepreneurship, and economic growth, with the priority and support that it requires?

Since universities will play such a critical role as the source of these assets of the age of knowledge, perhaps the university of the 21st century will also shift its intellectual focus and priority from the preservation or transmission of knowledge to the process of creation itself. But here lies a great challenge. As noted earlier, creativity and innovation are key not only to problem solving but more generally to achieving economic prosperity, social well being, and national security in a global, knowledge-driven economy. Yet, while universities are experienced in teaching the skills of analysis, we have far less understanding of the intellectual activities associated with creativity. In fact, the current disciplinary culture of our campuses sometimes discriminates against those who are truly creative, those who do not fit well into our stereotypes of students and faculty.

The university may need to reorganize itself quite differently, stressing forms of pedagogy and extracurricular experiences to nurture and teach the art and skill of creation and innovation. This would probably imply a shift away from highly specialized disciplines and degree programs to programs placing more emphasis on integrating knowledge. There is clearly a need to better integrate the educational mission of the university with the research and service activities of the faculty by ripping instruction out of the classroom–or at least the lecture hall–and placing it instead in the discovery and tinkering environment of studios or workshops or "hacker havens".

Drawing together aspects of hardware and software, inquiry and discovery, tinkering and invention, and creativity and innovation, experimentation and performance, the Duderstadt Center and Walgreen Center provide a tremendous interactive playground for imaginative scholars and students. The tools in these facilities are so easy to use that ideally they become natural extensions to everyday activity. For example, an artist, an engineer, and a choreographer should be able to think up a new staging for a performance together, sketch it out in three dimensions on a computer, then show it off and discuss it in real time with colleagues both here and across the world, all without noticing the complex technology that allows them to collaborate.

This model of "creativity and innovation" commons facilities that enable faculty members and students from diverse schools to work together is now being propagated to other parts of the University, including the arts and humanities and social sciences of the Central Campus and the natural sciences and biomedical programs.

This vision of "renaissance education" aligns well with several other aspects of the University's institutional saga such as its commitment to excellence and leadership and its belief that this rests upon building diverse learning communities. But achieving such a vision will also likely require a culture change that encourages risk taking and tolerates occasional failure as the price one must frequently pay for setting and accomplishing challenging goals.

Particularly key in this effort is the earlier goal of diversity. As Tom Friedman noted in a New York Times column,

"The sheer creative energy that comes when you mix all our diverse people and cultures together. We live in an age when the most valuable asset any economy can have is the ability to be creative–to spark and imagine new ideas, be they Broadway tunes, great books, iPads, or new cancer drugs. And where does creativity come from? To be creative requires divergent thinking (generating many unique ideas) and then convergent thinking (combining those ideas into the best result). And where does divergent thinking come from? It comes from being exposed to divergent ideas and cultures and people and intellectual disciplines." (Friedman, 2011) J

Actually, as John Seely Brown points out, today's students are already using technology to function much like artists – disciplined, focused, pushing boundaries, challenging assumptions and creating meaning. (Brown, 2009) They are willing to engage with multiple viewpoints before synthesizing their own. But beyond that, they look for meaning not just in what they create or own but in addition through what they contribute back to society-at-large. They are engaged, first and foremost, in fostering what might be called the creative class. Not only do they want to create for themselves, but they also want others to build on their creations.

The platforms they use are mostly digital: instant messaging to keep in constant contact with one's own intimate community; blogging to let one experiment by exposing their ideas to others and getting rapid feedback; by participating in the rapidly expanding worlds of open source, open content (e.g., Wikipedia), and remixing the work of others; rich media capable of expressing complex ideas; and a vast network characterizing cyberinfrastructure that lets one access communities, instruments, and databases all over the world (an infrastructure that the University of Michigan has played a key role in creating). These are the power tools of the Net Generation.

Enlightenment

Chapter 8

Universities and the Enlightenment

Today our world has entered a period of rapid and profound economic, social, and political transformation driven by knowledge and innovation. Educated people, the knowledge they produce, and the innovation and entrepreneurial skills they possess have become the keys to economic prosperity, public health, national security, and social well-being.

Yet the fundamental intellectual activities of discovery and learning that enable these goals are being transformed by the rapid evolution of information and communications technology. Although many technologies have transformed the course of human history, today the pace and impact of digital information technology is unprecedented.

Rapidly evolving digital technology consisting of hardware, software, people, and policies, has played a particularly important role, both in expanding our capacity to generate, distribute, apply knowledge. It has become an indispensable platform for discovery, innovation, and learning. This technology is continuing to evolve very rapidly, linking people, knowledge, and tools in new and profound ways, and driving rapid, unpredictable, and frequently disruptive change in existing social institutions. But since cyberinfrastructure can be used to enhance learning, creativity and innovation, intellectual span, and collaboration, it presents extraordinary opportunities, as well as challenges, to an increasingly knowledge-driven society.

Any vision proposed for the University of Michigan's future must consider the extraordinary changes and uncertainties of a future driven by exponentially evolving information and communications technology. The extraordinary connectivity provided by the Internet already links together the majority of the world's population. To this, one can add the emerging capacity to capture and distribute the accumulated knowledge of our civilization in digital form and provide opportunities for learning through new paradigms such as MOOCS , cognitive tutors, digital libraries, and collaboratories. This suggests the possible emergence of a new global society no longer constrained by space, time, monopoly, or archaic laws and instead even more dependent upon the generation of new knowledge and the education of world citizens. In such an era of rapid change, it has become the responsibility of democratic societies to provide their citizens with the learning opportunities they need throughout their lives, at costs they can afford, as a right rather than a privilege.

What the nation (and the world) needs today is a 21st century version of the Enlightenment movement of the 17th and 18th century that swept aside the divine authority of kings by educating and empowering the public, stimulating revolution, and creating the liberal democracies that now characterize most developed nations. Our nation and our world needs once again the "illumination" provided by distributing "the light of learning and knowledge" to counter the ignorance (e.g., today's "denier" culture) and address the challenges of our times.

An Enlightenment for the 21st Century

The goals of the early Enlightenment were to provide for a rational distribution of freedom, universal access to knowledge, and the formation of learning communities. Rational and critical thought was regarded as central to freedom and democracy. Knowledge and learning were regarded as *public goods*, to be made available through communities such as salons, seminars, and academies.

These dreams of the universal and the collective, L*iberte, Egalite, and Fraternite* for the French Revolution–or perhaps better articulated by Jefferson's opening words from our Declaration of Independence: "We hold these truths to be self-evident, that all men are created equal, that they are endowed by their Creator with certain unalienable Rights, that among these are Life, Liberty and the pursuit of Happiness."–remain as important today as they were three centuries ago.

Steven Pinker proposes that the ideals of the Enlightenment were *reason, science, humanism, and progress.* (Pinker, 2018) Our world today is largely a result of these ideals; the impact of the Scientific Revolution, the use of reason rather than mythology to understand our world, the importance of understanding human nature, and the objective of peace rather than conflict. The impact on our civilization over these two centuries has been stunning. Largely because of the themes of the Enlightenment, over the past two centuries the world has made spectacular progress in every measure of human well-being.

Today the educational institution most capable of launching a new "Age of Enlightenment" is the "university". In a sense, the word "university" itself conveys the elements of this vision: both the sense of a "union" or community of learners (i.e., *universitas magistrorum et scholarium*) and the "universality" or totality of knowledge and learning as the key to social well-being in an age of knowledge. Furthermore, since these have been regarded as *public* goods, one might even suggest that the *public* universities have a particular responsibility in providing these.

A Mission for Michigan

Our proposition is that the Enlightenment theme would be a particularly compelling and appropriate goal for the University of Michigan's third century. After all, our future will continue to be one in which freedom and prosperity depend upon widespread distribution of "the light of learning and knowledge", and hence this should become a key component of our extended public purpose.

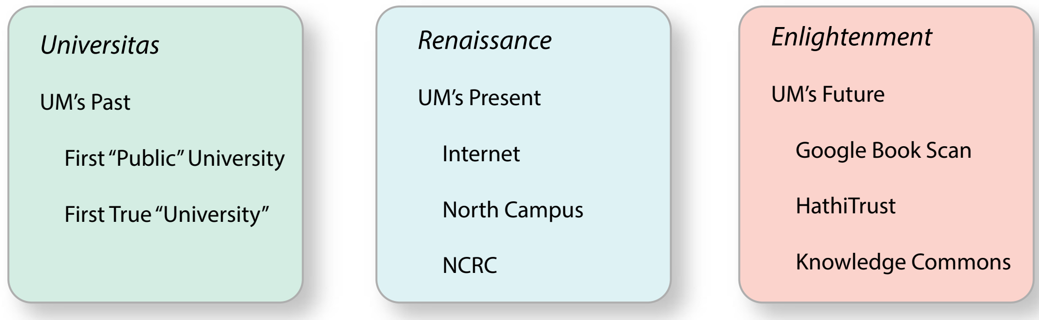
Actually, this theme traces its origin to the earliest days of the University of Michigan, since its original incarnation as "the Catholepistemiad or University of Michigania" was a utopian vision stimulated by the principles of the Enlightenment that undergirded the Northwest Ordinance of 1787, e.g., "religion, morality, and knowledge being necessary to good government and the happiness of mankind, schools and the means of education shall forever be encouraged".

Michigan's early evolution, heavily influenced by Henry Tappan's efforts to build a true university based not simply on learning but on scholarship ,laid this foundation for the research university in America. Particularly important was its public character was shaped by the Jeffersonian ideal of education for all to the extent of the individual's capacity, i.e., "providing an uncommon education for the common man". These fundamental principles, along with its unusual secular character, established Michigan as one of the nation's first and most prominent "public" "research" universities and continues to define its public purpose today in terms of both creating and distributing learning and knowledge to society. Hence, it is most appropriate that any vision for the University's future embrace and extend its character as a truly "public university" to address the nature of our changing world. (Peckham, 1964)

But while the Enlightenment of the 18th century was concerned with "celebrating the luminosity of knowledge shining through the written word", today knowledge comes in many forms–words, images, immersive environments, and virtual reality. Learning communities are no longer constrained by space and time but rather propagated instantaneously by rapidly evolving technologies (e.g., cyberinfrastructure) and practices (e.g., open source, open knowledge). The ancient vision of the Library of Alexandria to collect all of the books of the world in one place is rapidly becoming true–except the "place" has now become a cloud in cyberspace. Learning communities are evolving into knowledge generating communities–wikis, crowd sourcing, hive cultures that span the globe.

In a sense, the concept of a 21st century analog to the Enlightenment combines several themes that we suggested earlier might characterize the university of the future:

- The emergence of a *Universitas Magistrorum et Scholarium* in cyberspace.



Linking Future Themes to Past Accomplishments

- The power of network architectures in distributing knowledge and learning
- The increasing access to knowledge and learning resources through the massive digitization and access to printed materials and other sources of information
- The perspective of learning organizations as ecologies that evolve and mutate into new forms such as collaboratories
- The university as the prototype of an emergent global civilization

Today, the University of Michigan is already playing a leadership role in achieving just such a vision. Its efforts during the 1980s (together with IBM and MCI) to build and manage the backbone of the Internet, its role in creating Internet2, and new knowledge structures such as collaboratories, all provide strong evidence of the leadership role it plays in linking together people and institutions around the world.

The University of Michigan has also played a leadership role in redefining the nature of the "library" for a digitally connected world, first with the Mellon Foundation's JSTOR project, the first major effort to digitize a massive collection of scholarly publications in disciplines such as economics and history. Today, Michigan serves as the lead partner in the HathiTrust, a collection of 80 leading libraries with the further goal of providing full-text access to large inventories of scholarly materials. Its creation of the first School of Information provides an important new academic approach to learning and research in knowledge management. Furthermore through its academic innovation efforts, it is providing leadership to online efforts to provide global access to learning resources. The University has firmly established its leadership role in providing both knowledge and learning on an unprecedented global scale.

Hence, it is appropriate (and provocative) to suggest that the University is well-positioned to participate in a contemporary version of the Enlightenment, spreading knowledge and learning throughout the world. We suggest that this might become the primary mission of the University for its Third Century!

This suggests three visions for the future of the University of Michigan:

A vision for today of *Universitas* upon the past accomplishments, values, and key characteristics of the University's institutional saga.

A near-term vision of a *Renaissance* as the University aligns itself to better engage with a world dependent upon learning, knowledge, creativity, and innovation by spanning the broad range of learning from simply" to know", "to do", "to create", and "to become; and

A longer term vision of *Enlightenment* as the University commit itself to expand its public purpose to provide "the light of learning an knowledge" to the world in the new forms enabled by rapidly evolving information and communications technologies, i.e., cyberinfrastructure.

The Changing Nature of Discovery, Learning, and Innovation

The fundamental intellectual activities of discovery and learning enabling these goals are being transformed by the rapid evolution of information and communications technology. Rapidly evolving digital technology, so-called cyberinfrastructure, consisting of hardware, software, people, and policies, has become an indispensable platform for discovery, innovation, and learning. This technology is continuing to evolve very rapidly, linking people, knowledge, and tools in new and profound ways, and driving rapid, unpredictable, and frequently disruptive change in existing social institutions. But since cyberinfrastructure can be used to enhance learning, creativity and innovation, intellectual span, and collaboration, it presents extraordinary opportunities as well as challenges to an increasingly knowledge-driven society.

Clearly, today cyberinfrastructure continues not only to reshape but actually create new paradigms for learning and discovery not only in the sciences but increasingly also in the humanities and arts. This is particularly true for emerging technologies such as always-on, ubiquitous connectivity (anywhere, anytime, everyone); social networking, crowd sourcing, collaborative learning and discovery, functionally complete cyberinfrastructures, emerging learning paradigms such as massively open online courses, cognitive tutors, gaming, immersive experiences; big data, data-intensive discovery, learning analytics, intelligent software agents, and possible surprises such as cognitive implants. Of particular concern is the impact of emerging technologies to transform learning institutions (schools, colleges, workplace training, lifelong learning, open learning) and paradigms (from learning about, to learning to do, to learning to become).

The evolution of powerful cyberinfrastructure is driving major change in the paradigms for discovery and research. Artificial intelligence and ata mining has been added to the traditional scientific processes of observation, hypothesis, and experiment, becoming more data driven rather than hypothesis driven. Both fundamental research and product development are increasingly dependent on simulation from first principles rather than experimental measurement testing, requiring massive supercomputers. If one subscribes to the view that there is a paradigm shift from hypothesis driven to data-driven discovery and simulation, then it is clear that the entire conduct and culture of learning, discovery, and innovation is changing as a result of access to data, technology and social networks. We are going to need new models for sharing data, software, and computational resources.

The impact of rapidly evolving cyberinfrastructure on research and scholarship has been experienced across all of the academic disciplines, e.g., the natural and social sciences, the arts and humanities, and particularly the professional discipline. New paradigms are rapidly emerging for learning and education as well as innovation and professional practice.

William Germano suggests yet another profound element of the new cyberinfrastructure-based "enlightenment":

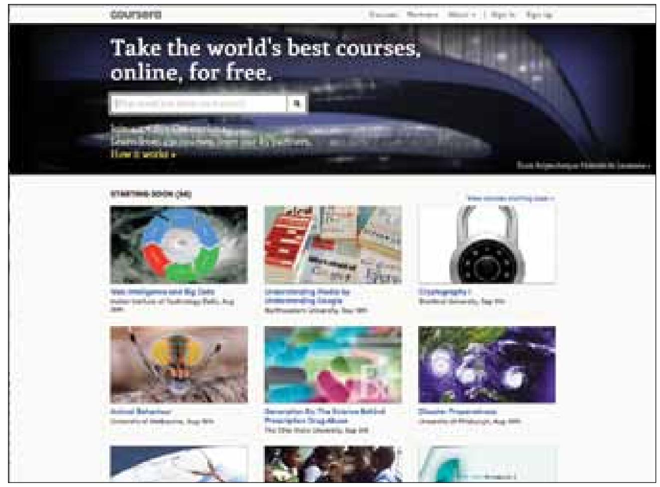
"Right now we are walking through two great dreams that are shaping the future of scholarship, even the very idea of scholarship and the role "the book" should play within it. Great Dream No. 1 is universal access to knowledge. This dream means many hings to many people, but for knowledge workers it means that scholarly books and journals can, and therefore should be made available to all users. New technologies that make that possible for the first time in human history, and as the argument goes, the existence of such possibilities obligates us to use them. Great Dream No. 2 is the ideal of knowlege building as a self-correcting, collective exercise. Twenty year ago, nobody had Wikipedia, but when it arrived it took over the hearts and laptops for undergraduates and then of everyone else in the education business. Professional academic life would be poorer, or at least much slower, without it. The central premise of Wikipedia isn't speed but infinite self-correction, perpetually fine-tuning what we know. In our second dream, we expand our aggregated knowledge quantitatively and qualitatively." (Germano, 2010)

Paradigm Shifts

The Common Denominators

As knowledge and educated people become key to prosperity, security, and social well-being, the university, in all its myriad and rapidly changing forms, has become one of the most important social institutions of our times. Yet many questions remain unanswered. Who will be the learners served by these institutions?

MIT's OpenCourseware Project



Coursera MOOCs

Who will teach them? Who will administer and govern these institutions? Who will pay for them? What will be the character of our universities? How will they function? When will they appear? The list goes on.

It is difficult to suggest a particular form for the university of the 21st Century. The ever-increasing diversity of American higher education makes it clear that many types of institutions will serve our society. Nonetheless, a number of themes will almost certainly characterize at least some part of the higher education enterprise:

- Universities will shift from faculty-centered to *learner-centered* institutions, joining other social institutions in the public and private sectors in the recognition that we must become more focused on those we serve.
- They will be more *affordable*, within the resources of most citizens, whether through low cost or societal subsidy.
- They will provide *lifelong learning*, requiring both a willingness to continue to learn on the part of our citizens and a commitment to provide opportunities for this lifelong learning by our institutions.
- All levels of education will be a part of a *seamless web*, as they become both interrelated and blended together.
- Universities will embrace *asynchronous learning*, breaking the constraints of time and space to make learning opportunities more compatible with lifestyles and needs, anyplace, anytime.
- We will continue to develop and practice *interactive and collaborative learning*, appropriate for the digital age, the "plug and play" generation.
- Universities will commit to *diversity* sufficient to serve an increasingly diverse population with diverse needs and goals.
- Universities will need to build learning environments that are both *adaptive and intelligent*, molding to the learning styles and needs of the students they serve.

There is one further modifier that may characterize the university of the future: *ubiquitous*. Today, knowledge has become the coin of the realm. It determines the wealth of nations. It has also become the key to one's personal standard of living, the quality of one's life. We might well make the case that today it has become the responsibility of democratic societies to provide their citizens with the education and training they need throughout their lives, whenever, wherever, and however they desire it, at high quality, and at a cost they can afford.

Of course, this has been one of the great themes of higher education in America. Each evolutionary wave of higher education has aimed at educating a broader segment of society—the public universities, the land-grant universities, the normal and technical colleges, and the community colleges. But today we must do even more to serve an even broader segment of our society.

Google Books

Hathi Trust

New Learning Paradigms

The current strong interest (and hype) concerning massively open online courses (MOOCs) provides an example of how the merging of ubiquitous connectivity, social networking, and sophisticated pedagogy can create new forms of learning that access massive markets. Developed originally by computer scientists, the online paradigm has rapidly been extended in numerous disciplines to massive markets by many universities working through integrators such as Udacity, Coursera, and EdX. While there are still many questions both about the rigor of the online MOOC pedagogy and its capacity to generate revenues for the host institutions, it nevertheless provides an example of how robust connectivity leveraged through social networks can create massive learning communities at a global level.

Of course, today's MOOCs do have some new elements, aside from the massive markets they are able to build through the Internet and their current practice of free access. (Waldrop, 2013) They augment online broadcast of canned lectures and automated grading of homework with social networks to provide teaching support through message boards and discussion groups of the students themselves. Their semi-synchronous structure, in which courses and exams are given at a specific time while progress is kept on track. Here one might think of MOOCs as a clever combination of the United Kingdom's Open University (online education) and Wikipedia (crowd sourcing of knowledge)! Furthermore, MOOCs, such as Carnegie Mellon's far-more sophisticated Open Learning Initiative, are able to use data mining (analytics) to gather a large amount of information about student learning experiences. When combined with cognitive science, this provides a strong source of feedback for course improvement.

Some believe that today higher education is on the precipice of an era of extraordinary change as such disruptive technologies challenge the traditional paradigms of learning and discovery. (Friedman, 2011) They suggest that new technologies could swamp the university with a tsunami of cheap online courses from name-brand institutions, or adaptive learning using massive data gathered from thousands of students and subjected to sophisticated analytics, or even cognitive tutors that rapidly customize the learning environment for each student so they learn most deeply and efficiently.

But are these really something new or rather simply old wine in new bottles? After all, millions of students have been using online learning for decades (estimated today to involve over one-third of current students in the United States). There are many highly developed models for online learning, including the UK Open University, the Western Governor's University in the United States, and the Apollo group's global system of for-profit universities. Many of the buzzwords used to market these new technologies also have long established antecedents: Experiential learning? Think "laboratories" and "internships" and "practicums"…

and even “summer jobs”! Flipped classrooms? Think “tutorials” and “seminars” and “studios”. Massive markets of learners? Many American universities were providing free credit instruction to hundreds of thousands of learners as early as the 1950s through live television broadcasts!

Certainly the MOOC paradigm is characterized by a powerful delivery mechanism. But it is just one model. There are also other models to explore and rich collaboration opportunities to share such as the data analytics and adaptive learning used in Carnegie Mellon’s Open Learning Initiative or the artificial intelligence-based cognitive tutor technology, developed again by Carnegie Mellon, and used in K-12 and lower division college education for the past decade. Other approaches include open knowledge initiatives such as Google Books, the HathiTrust, and open scholarly data and publication archives; massively player gaming (e.g., Minecraft and the World of Warcraft) and immersive media (e.g., Second Life, and Enders Game). Automated assessment and evaluation could turn the whole education business upside down because we will have access to massive data sets that potentially will give us some insight in not how we deliver content but rather how people learn.

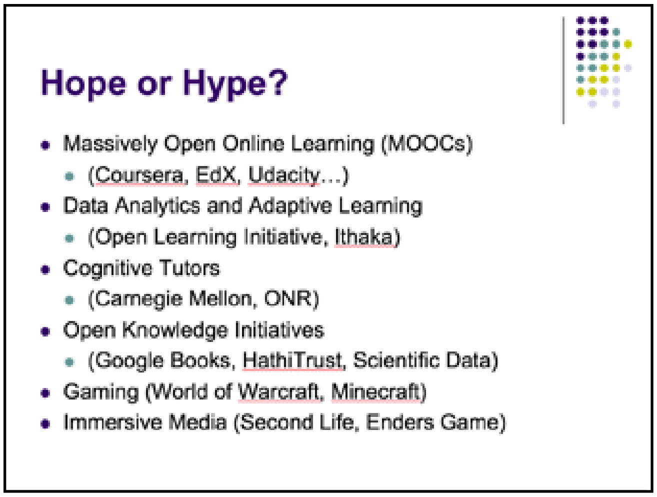
It is likely that AI-based online learning will be a disruptive technology, and that analytics on learning data holds considerable promise. But it is also very important to separate the fundamental character of a college education from the specific resources used to achieve that, e.g., courses and curricula, textbooks and course notes, faculty and laboratory staff, and, of course, the complex learning communities that exist only on university campuses. After all, most of today’s online learning is marketed as courses, not as a college education. We must remember the current university paradigm of students living on a university campus, completely immersed in an exciting intellectual and social physical environment and sophisticated learning communities, provides a very powerful form of learning and discovery. MOOC, intelligent Tutors, and xR based online learning are interesting approaches, but they are far from the vibrant, immersive environment of a college education, at least as we understand it today.

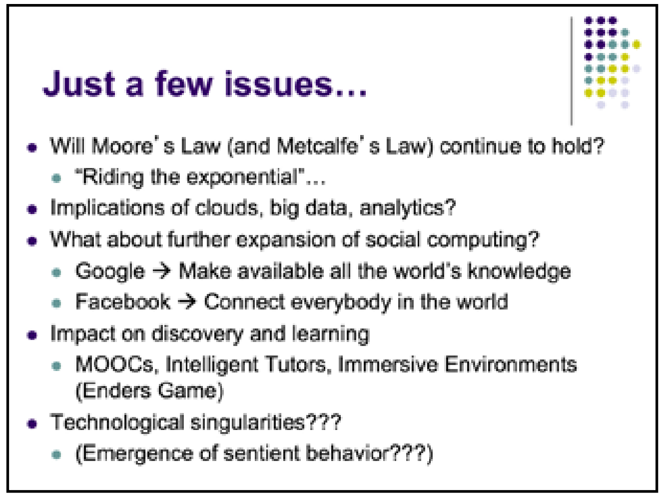
What do we know about the effectiveness of these technology-based approaches? Where are the careful measurements of learning necessary to establish the value of such forms of pedagogy? Thus far, promoters have relied mostly on comparisons of performances by both conventional and online students on standard tests. The only serious measurements have been those that Ithaka has conduced on the learning by cognitive tutor software in a highly restricted environment. (Bowen, 2012)

Of course, there are highly disruptive scenarios. So, what are the opportunities presented by cyberinfrastructure for learning and teaching. Some believe that today higher education is on the precipice of an era of extraordinary change as such disruptive technologies challenge the traditional paradigms of learning and discovery. They suggest that new technologies could swamp the university with a tsunami of cheap online courses from name-brand institutions, or adaptive learning using massive data gathered from thousands of students and subjected to sophisticated analytics, or even cognitive tutors that rapidly customize the learning environment for each student so they learn most deeply and efficiently, entirely without the involvement of faculty.

It is likely that recent online approaches such as micro-masters (e.g., partial online courses as a component of traditional degrees) are a disruptive technology, and that analytics on learning data holds considerable promise. But it is also very important to separate the fundamental character of a college education from the specific resources used to achieve that, e.g., courses and curricula, textbooks and course notes, faculty and laboratory staff, and, of course, the complex learning communities that exist only on university campuses. After all, MOOCs are marketed as courses, not as a college education. We must remember that the current university paradigm of students living on a university campus, completely immersed in an exciting intellectual and social physical environment and sophisticated learning communities, provides a very powerful form of learning and discovery.

There is also a big difference between the perspective of the providers of online learning and the students who are their consumers. Right now, we are watching the providers figure out what they are going to do, with strong investments from the venture capital community and for-profit education providers





suggesting that at least some people believe they might become very rich from these gigantic educational markets. Furthermore, today's online courses are aimed primarily at individuals, not communities. There is a huge challenge thinking about what they will mean in the university, and whether the second tier institutions can use off-the-shelf online courses and do something with them to reduce cost or bring in new kinds of students. But there are many questions. What happens to faculty governance issues? What about copyright issues? Who owns these courses? Are all of the professors going away, replaced by MOOC broadcasts from star teachers and using crowd sourcing to grade and answer questions?

Finally, we should remember that this new paradigm is being launched by several of the most elite and expensive private universities in America (e.g., Stanford, Harvard, and MIT) using both the Internet and social media as well as their powerful brand names to build mammoth markets for their MOOC companies (Udacity, Coursera, EdX) in an effort to eventually create new revenue streams to subsidize the rapidly rising costs of more traditional, highly expensive education on their own campuses. A related concern is that the intense media hype given these new learning paradigms has put enormous pressure on public colleges and universities from governing boards and state governments attempting to reduce the costs of college education, even at the sacrifice of educational equality. It would be tragic if technology-based paradigms such as MOOCs were to drive even greater inequities in higher education.

There are already many warning signs about the effectiveness of massively open online courses. More than half of those who register for MOOCs never complete the courseware. There is also a sharp dropoff after the first year of the course, with only 12% of the largest cohort taking a second course. The large MOOC providers such as EdX, Coursera, and Udacity are now beginning to work with universities to build paywalls around their content. Instead they are beginning to focus on credit-based professional masters programs, particularly in fields such as business education. Indeed, several universities are beginning to move away from oncampus instruction in professional areas to provide instead online based credit courses such as the "micro-masters" taken by students in the workplace as part of the requirements for the MBA.

Of course, it eventually comes back to the questions of "What is the most valuable form of learning that occurs in a university…and how does it occur?" Through formal curricula? Through engaging teachers? Through creating learning communities? After all, the graduate paradigm of *Universitas Magistrorum et Scholarium* involving the interaction of masters and scholars will be very hard to reproduce online…and least in a canned video format!!!

As William Bowen, former president of Princeton and the Mellon Foundation and a founder of Ithaka suggests, it is time to "Walk, Don't Run" toward the use of cyberlearning. We need lots of experimentation, including rigorous measurement of education–before we allow the technology tsunami to sweep over us!

New Paradigms for Research and Scholarship

Is the Paradigm for Basic Research Really Changing?

Are the paradigms characterizing research and scholarship paradigms also shifting with emerging technologies? Certainly the language of research is changing to embrace concepts such as clouds, data mining, collaboratories, etc. If one subscribe to the view that there is a paradigm shift from hypothesis-driven to data-correlation-driven discovery, then the culture of scientific and engineering discovery and innovation is changing as a result of access to data, computational technology, and social networks. We are going to need new models for sharing data, software, and resources such as computational technology

But is the way in which research is conducted changing? What about global competition? Is the world of facilities-intensive big science, such as high-energy physics, sustainable when it requires sending faculty and students to the only places capable of conducting the research (e.g., CERN), resulting in a list of authors longer than substance of the papers? Are we moving to a "wiki" world where crowd sourcing of amateurs becomes important for scientific research? How important is the role of research and scholarship within universities? Do we need tweaking of tax laws so the translational research characterizing earlier paradigms, such as Bell Laboratories, begin to reappear as part of the knowledge ecosystem?

Universal Access to Knowledge and Learning

Ironically, while we generally think of cyberinfrastructure in terms such as terabit/sec networks and exaflop supercomputers, the most profound changes in our institutions may be driven not by the technology itself but rather by the philosophy of openness and access it enables– indeed, imposes–on its users. Of particular importance are efforts to adopt the philosophy of open source software development to create new opportunities for learning and scholarship for the world through open educational resources by putting previously restricted knowledge into the public domain and inviting others to join in both its use and development. (Atkins, 2007)

To this array of open educational resources should be added efforts to digitize massive quantities of printed material and make it available for search and eventual access. For example, the HathiTrust now involves over 80 universities with a collection of roughly 18 million volumes. While many copyright issues still need to be addressed, it is likely that these massive digitization efforts will be able to provide full text access to a significant fraction of the world's written materials to scholars and students throughout the world within a decade.

Academic Innovation at Michigan

For the past several decades the University of Michigan has provided leadership in the creation of digital technologies for both oncampus instruction and remote learning. In the 1990s it develop Sakai and CTools software packages for course management that were widely used both by the University and many other institutions. When concern arose about the degree to which the early MOOC providers such as Coursera, Edx, and Udacity retained control of intellectual property developed by universities for their online courses, Michigan led the effort to create a new MOOC organization, Unizen, now consisting of 80 universities, that enabled institutional control of intellectual property.

Led by James Hilton as Vice Provost for Academic Innovation and James Devaney as Associate Vice Provost for Academic Innovation, the University created a complete portfolio of activities, ranging from the conducting the research to gather educational data to developing tools for learning to curricular innovation. Today these activities have been used by over 200 countries and created 7.3 million enrollments in UM's instructional activities. They have also involved over 160 faculty and guest scholars in the development of what is now titled as Michigan Online.

Yet the mission of UM Academic Innovation is far broader, extending from the support of pre-college learning (broadening access and enhancing participation) to residential oncampus learning to global and lifelong learning and public engagement. The efforts of the organization recognize that in a

James Hilton

James Devaney

Daniel Fessahazion

world in which lifelong learning becomes a global need of society in a rapidly changing technological environment, such a pervasive approach is urgently needed.

UM Academic Innovation focuses its activities–and the development of institutional capabilities in three primary areas: i) educational data and research, ii) the development of tools for learning, and iii) developing technology intensive approaches to curricular innovation such as MOOCs, MicroMasters, Teach-Outs, and Online Degrees. While many other universities have created similarly comprehensive capabilities in some of these areas, the UM Academic Innovation activity is unique in its comprehensiveness.

For example, it uses shared and scaled digital repositories such as the Hathitrust to build teaching and learning ecosystems, combining content (e.g., from digital libraries) to applications (e.g., lectures, labs, discussions) to outcomes (concept mastery, critical thinking).

Michigan Online has developed strong capabilities in data and learning analytics, working with other net-based learning systems such as Coursera and edX. However it has gone further by creating a new data platform, Unizin, that has the advantage of allowing participants to continue to own the intellectual property they development for their online efforts. Currently Unizin has 13 participating institutions involving 1.2 million students and 22 million enrollments.

Michigan Online has developed an array of tools designed for online learning:

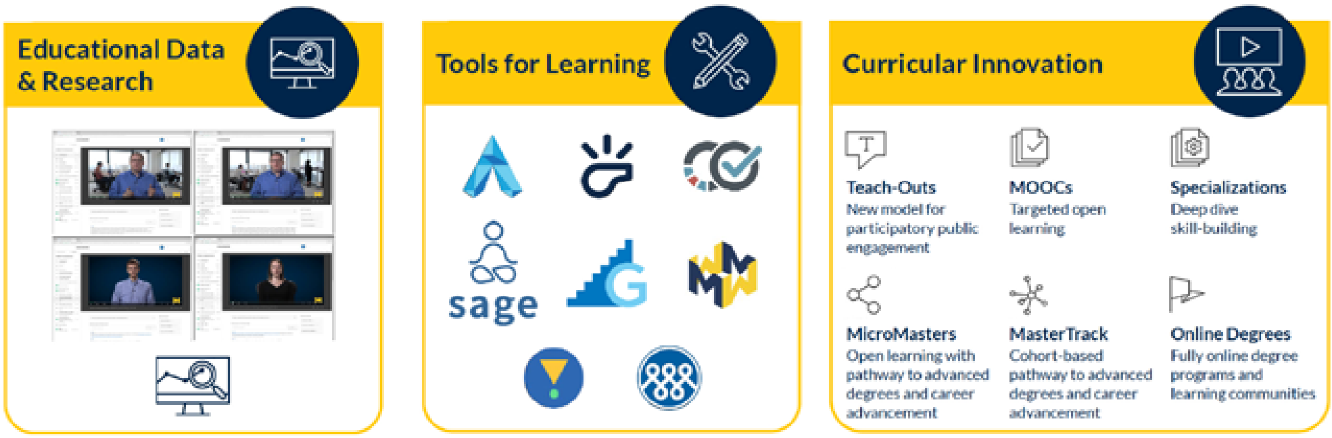
Art 2.0: Academic Data to make Choices
ECoach: Personalized Messaging to Students
Gradecraft: Gameful Pedagogy for Learning
Health Minds: Personalized Wellness Support
M-Write: Writing-to-Learn Pedagogies
Problem Roulette: Practice Problems for Exams
ViewPoint: Role-playing Simulations
Wireless Indoor Location Device: Learning

Over the past decade, the Academic Innovation Division has developed a number of major new applications for curriculum innovation

Teach-Outs: Participatory Public Engagement
MOOCS: Targeted open learning
MicoMasters: Open learning with pathway to advanced degrees and careers
MasterTrack: Cohort-based pathway to advanced degrees and careers
Online Degrees: Fully online degree programs and learning communities

While the Academic Innovation office is continuing to grow its MOOC portfolio through partnerships with Coursera and edX, it is also experimenting with a new ecology of credentials by developing MOOC series, MicroMasters, and MasterTrack certificate programs. These flexible and stackable portfolios of offerings support residential, online, and lifelong learning opportunities for a rapidly growing learning community, both online and oncampus.

As shown in the tables, the rate of participation in



Areas of focus for the UM Division of Academic Innovation

these programs has been extensive. Perhaps of equal importance, however, is the rate of development of new approaches to lifelong and global learning applications with very significant cost advantages. The rate of development and adoption of these applications has motivated the University in 2018 to create an online access to its Academic Innovation activities labeled as Michigan Online.

The University has long been involved in the development of virtual reality technology the Office of Academic Innovation to assist its academic units in implementing this powerful new technology for learning and scholarship. The Duderstadt Center has already created a major new Visualization Laboratory for A&VR training and development, while the move of the School of Information adjacent to the College of Engineering's Department of Computer Science and Information will provide a concentration of faculty and students conducting research in A&VR.

The Office of Academic Innovation was also expanded with 40 additional staff to broaden its roles as part incubator, part internal consultancy, and part design lab in this area (now designated as "xR" or "extended reality") rX encompases augmented reality, virtual reality, mixed reality and other variations of these forms of computer-generated real and virtual combined environments and human-machine interactions.

The Michigan effort will be to explore how these new technologies can enhance its educational efforts, cultivating an interdisciplinary scholarly community of XR practice, and enhance a nationwide network for academic innovation. A campus-wide approach will be taken, involving many disparate disciplines and environments including the arts and humanities.

University activities in visualization, virtual reality, and xR

University activities in visualization, virtual reality, and xR

Concerns for the Future

The primary missions of the university, its teaching, research, and service activities (or alternatively, its activities of learning, discovery, and engagement with society) are increasingly dependent on cyberinfrastructure, i.e., information and communications technology. The rapid advances in these technologies are not only reshaping but creating entirely new paradigms for research, education, and application not only in science and engineering but in all of the academic and professional disciplines. It has been clear for sometime that to maintain world-class academic programs, universities must also achieve leadership in the quality and relevance of the cyberinfrastructure it provides at the level of each of its highly diverse teaching and research programs.

This is particularly challenging since the features of information technology such as processing speed, memory, and bandwidth, have been increasing in power at rates of 100 to 1,000 fold per decade since WWII. This is one of the major reasons for the continued surprises we get from the emergence of new applications–the Internet, social networks, big data, machine learning–appearing in unexpected ways at a hyper exponential pace. We have learned time and time again that it makes little sense to simply extrapolate the present into the future to predict or even understand the next "tech turn". These are not only highly disruptive technologies, but they are highly unpredictable. Ten years ago nobody would have imagined Google, Facebook, Twitter, etc., and today, nobody really can predict what will be a dominant technology even five years ahead, much less ten!

Fortunately, the University of Michigan has been able to respond to such rapid technological change in the past–and, indeed, achieved leadership–because it has functioned as a loosely coupled adaptive system with many of its academic units given not only the freedom, but also the encouragement, to experiment and to try new things. It is at the level of academic units rather than the enterprise level where innovation and leadership must occur. Why? Because they are driven by learning and discovery, by experimentation, by tolerance for failure, and by extraordinarily talented faculty, students, and particularly, staff. While perhaps locating a computing cluster in every closet is not very efficient, it has made MIT, Carnegie Mellon, and Stanford leaders, as well as Michigan with CAEN and MERIT (i.e., NSFnet and then the Internet).

At a NSF sponsored conference on the role of cyberinfrastructure in discovery and learning hosted by the University, many participants stressed the importance of "craft", of the contributions of truly talented staff who drive innovation in units where they are most competent (Atkins, 2013). These people are attracted to universities such as Michigan to work in academic units with faculty and students where they are highly valued and have the freedom to do exciting work. In fact, its great strength and contribution to society arises from this very unusual diversity in ideas, experiences, and people. Again, this argues for an organic plan, essentially a diverse ecosystem that will continue to mutate and evolve in ways that we cannot anticipate.

In the past, the university has intentionally avoided the dangers of centralizing these activities, although every once in awhile the central administration will launch attempts to centralize what is inherently a highly decentralized technology. s.

The tension between centralization and decentralization (where cacophony leads to innovation) can be very threatening, particularly to those parts of the university that need to make the trains run on time (e.g., financial services, hospitals, etc.) Fortunately, in the past, the wisdom of maintaining a loosely coupled adaptive system at the academic level finally bubbles up to the leadership of the institution, and academic units are set free once again. To be sure, the university has important responsibilities that require mission critical computing. But it is at the level of academic units rather than the enterprise level where innovation and leadership must occur. Why? Because they are driven by learning and discovery, by experimentation, by tolerance for failure, and by extraordinarily talented faculty, students, and particularly, staff.

Just what purposes should drive IT strategy. To support the university mission? What mission? Of the University writ large? Of the academic units? Of generic language like teaching, research, and service… or discovery, learning, and engagement…or "Change the world!"…or what?

Should academic institutions attempt to centralize all IT commodity services? In a loosely coupled adaptive system, one may need a more evolutionary system to do this, which taps bottom-up rather than top-down perspectives.

What should be the focus on solutions that are easily created and replaced? Agility to be sure. But what about resilience? And maturity? What about "optimum redundancy", so important to academic processes. For example, while many universiteis have committed at the enterprise level to Google, this is a company that still has not grown up yet to understand much less embrace "mission critical" applications such as university instruction. We need to be careful about becoming overly dependent on adolescents (at least it so appears from a visit to the GooglePlex).

What is the appropriate strategy for enterprise-wide IT development? Many universities focus on providing a cyberinfrastructure environment on campus. But the anyplace-anytime character of today's world leaves hanging the majority of the time spent working by our students, faculty, and staff, which is off campus in their homes, dorms, cars, wherever. Without a major plan for high-speed connectivity throughout the community, this is a very incomplete strategy. Hence, without robust connectivity beyond the campus, these major investments will fall far short of our needs.

And how can centralization of the cyber experience handle the extraordinary diversity of the academic programs. The university in general–and Michigan in particular–is one of the most intellectual diverse organizations in the world. In fact, its great strength and contribution to society arises from this very unusual diversity in ideas, experiences, and people. Again, this argues for a much more organic plan, essentially a diverse ecosystem that will continue to mutate and evolve in ways that we cannot anticipate.

As an example, the learning paradigm varies enormously across campus, from the general education of young students to disciplinary concentrations (compare deconstructing a poem with proving a theorem in algebraic topology) to professional education (operating on a patient or arguing a case before a court or building and testing a drone design). Too much of centralized strategy is focused on undergraduate education as if we were primarily a "college". But universities are quite a different intellectual entities. Again, "seamless learning", "emerging learning modalities", etc., are not only buzz words but sound more appropriate for young K-12 learners than for the *Universitas Magistrorum et Scholarium* that characterizes one of the world's great research universities.

Where is the subject of institutional collaboration? Today our faculty work more with colleagues on the other side of the globe than across the hall; our students bring multi-institution study groups with them from their high school days…and Facebook, of course…most of our faculty are nomadic, moving from institution to institution every few years, just as our students will move on to other endeavors and institutions when they finish their studies. Again, more consideration needs to be given of life beyond the campus...and with institutions beyond our own.

Too much of the current focus is shaped by today's technologies, not tomorrows. Cloud services, big data, analytics. Again, overdependence on commodity products, particularly to the degree we constrain the cyber environments of academic units through policies such as purchasing and shared services, will harm the loosely coupled adaptive culture of the university that is one of our greatest strengths. This is particularly dangerous if we become overly dependent on particular vendors because of top-down rather than bottom-up forces. The reality is (and always has been) that it has been our faculty, staff, and students who spot the next big trends in technology and then drive change upward through the institution.

It is becoming increasingly clear that we are approaching an inflection point in the potential of rapidly evolving information and communications technology to transform how the scientific and engineering enterprise does knowledge work, the nature of the problems it undertakes, and the broadening of those able to participate in research activities.

Of course, the impact of rapidly evolving cyberinfrastructure on research and scholarship has been experienced across not only all of the academic disciplines (e.g., the natural and social sciences and the arts and humanities), but throughout the professional disciplines as well. New paradigms are rapidly emerging as well for learning and education as well as innovation and professional practice such as open learning initiatives and immersive learning environments. The challenge for discovery and learning is to use cyberinfrastructure as a platform for enhancing knowledge communities and for expanding their scope and participation unconstrained by time and distance by stressing the interconnection between learning about, learning to do, and learning to be, eventually becoming a member of a community of practice.

To quote Arden Bement, former NSF Director, "We are entering a second revolution in information technology, one that may well usher in a new technological age that will dwarf, in sheer transformational scope and power, anything we have yet experienced in the current information age" (Bement, 2007). The implications of such rapidly evolving technology for the future of the discovery, innovation, and learning are of great importance to the prosperity, health, and security of our nation as it faces the challenge of an increasingly knowledge- and innovation-driven world. Such cyberinfrastructure will not only be increasingly important to higher education, but it will drive the evolution of the university as a knowledge institution.

Change and the University

History provides many examples of the ability of the university to adapt to change. Five centuries ago some suggested that the medieval university would not survive the printing press since people could learn by reading books rather than attending lectures. More recently, a decade ago, MIT's OpenCourseWare initiative to place the digital assets for all of their courses, 2,000 in number, in the public domain stimulated similar fears this would sink the universities and create a $2 trillion for-profit education economy. But once again, universities floated through this technology turn without major change.

In fact, the university today looks very much like it has for decades–indeed, centuries--in the case of many ancient European universities. It is still organized into academic and professional disciplines; it still bases its educational programs on the traditional undergraduate, graduate, and professional discipline curricula; and the university is still governed, managed, and led much as it has been for ages. We can always explain this by falling back on that famous quote of Clark Kerr: "About 85 institutions in the Western World established by 1520 still exist in recognizable forms, with similar functions and with unbroken histories, including the Catholic Church, the Parliaments of the Isle of Man, of Iceland, and of Great Britain, several Swiss cantons, and…70 universities." (Kerr, 2001)

But if one looks more closely at the core activities of students and faculty, the changes over the past decade have been profound indeed. The scholarly activities of the faculty have become heavily dependent upon digital technology–rather cyberinfrastructure–whether in the sciences, humanities, arts, or professions. Although faculties still seek face-to-face discussions with colleagues, these have become the booster shot for far more frequent interactions over the Internet. Most faculty members rarely visit the library anymore, preferring to access digital resources through powerful and efficient search engines. Some have even ceased publishing in favor of the increasingly ubiquitous digital preprint or blog route. Student life and learning are also changing rapidly, as students bring onto campus with them the skills of the net generation for applying this rapidly evolving technology to their own interests, forming social groups through social networking technology (Facebook, Twitter), role playing (gaming), accessing web-based services, and inquiry-based learning, despite the insistence of their professors that they jump through the hoops of the traditional classroom paradigm.

In one sense, it is amazing that the university has been able to adapt to these extraordinary transformations of its most fundamental activities, learning and scholarship, with its organization and structure largely intact. Here one might be inclined to observe that technological change tends to evolve much more rapidly than social change, suggesting that a social institution such as the university that has lasted a millennium is unlikely to change on the timescales of tech turns, although social institutions such as corporations have learned the hard way that failure to keep pace can lead to extinction. Yet, while social institutions may respond more slowly to technological change, when they do so, it is frequently with quite abrupt and unpredictable consequences, e.g., "punctuated evolution".

It could also be that the revolution in higher education is well underway, at least with the early adopters, and simply not sensed or recognized yet by the body of the institutions within which the changes are occurring. Universities are extraordinarily adaptable organizations, tolerating enormous redundancy and diversity.

Admittedly, it is also the case that futurists have a habit of overestimating the impact of new technologies in the near term and underestimating them over the longer term. There is a natural tendency to implicitly assume that the present will continue, just at an accelerated pace, and fail to anticipate the disruptive technologies and killer apps that turn predictions topsy-turvy. Yet, we also know that far enough into the future, the exponential character of the evolution of Moore's Law technologies such as info-, bio-, and nano- technology makes almost any scenario possible. (Kurzweil, 2005)

The Roadmap to *Enlightenment*

The final vision proposed for the University is the theme of Enlightenment, spreading the light of learning and knowledge to the world, as its public purpose for its third century. Here we suggest major elements of a possible roadmap to this future based upon several of the paradigms discussed in Chapter 5:

- The emergence of a *universitas magistrorum et scholarium* in cyberspace.
- The power of network architectures in distributing knowledge and learning
- The perspective of learning organizations as ecologies that evolve and mutate into new forms
- The university as the prototype of an emergent global civilization

Of course the themes we have suggested for comprising at least a rough roadmap to the Enlightenment vision of the University of Michigan's third century are highly speculative if not utopian in nature. They need to be better defined, refined, and translated into practical steps that the University can begin to take. But such is the case with any bold vision. And, interestingly enough, the University is already taking important steps down the path sketched out by this roadmap.

Capturing and distributing knowledge to the world: We have noted the leadership role that the University has in the massive digitization of printed materials and the use of these digital repositories (e.g., JSTOR, Google Book, HathiTrust). In fact, since the University's leadership of the HathiTrust has led to it creating the largest digital library in the world, one might suggest that Michigan is already serving as the nucleus of what may become a 21st century analog to the great Library of Alexandria.

The University is also playing an important leadership role in the open resource movement, using its influence to push for open access to research data and other scholarly materials. Finally, its School of Information, one of the first such academic programs merging traditional library science with informatics and other digital age technologies, provides leadership in both education and research in areas that will be critical to unprecedented access to the world's knowledge. Of particular important is the role of Michigan Publishing with its new ventures in open access publishing for scholars.

Open Education Resources: Although the University has some participation in efforts such as the OpenCourseWare movement and digital course development and distribution through vendors such as iTunes, Amazon, and other mechanisms, its recent involvement is limited to only a few academic units (most notably the School of Medicine). However, the University's involvement in new efforts such as massively open online courses (MOOCs) through organizations such as Unizen and Coursera will hopefully catalyze a greater leadership role in these important areas.

Cyberinfrastructure: In recent years, the University has once again begun to develop strategies and make investments to restore the position of leadership it once had in developing and deploying advanced cyberinfrastructure in partnerships with leading IT companies. Here the University must embrace a balanced strategy, both utilizing advanced technology in an efficient and cost-effective manner, and partnering with leading companies in both technology development and application for academic environments (much as it has in the past through efforts such as MTS, CAEN, NSFnet, Internet2, and Sakai).

Networking: Clearly advanced network development is key to the Enlightenment vision. The University has long had leadership in the development of national and international networks (e.g., NSFnet, the Internet, Internet2). Yet, simply providing high-speed network links between campuses and other knowledge institutions is only the first step, since such connectivity must be distributed to the desktop, laptop, and laboratory on the campus and to the homes of faculty and students in the surrounding community. Here the University is also participating in the Gig U effort to assemble a coalition of the nation's leading research universities to challenge industry (e.g., carriers such as AT&T, Verizon, and Comcast and technology companies such as Google and IBM) to provide ultra-high bandwidth connectivity through the campuses and surrounding communities (much like the Goggle community fiber program).

Advanced Learning Environments: The University should launch a major effort to develop and deploy advanced learning environments–particularly those enabling social networking and immersive environments (including "sim-stim"–high fidelity simulation of all the senses at a distance). Its past experience with the development of open source curriculum management software such as CTools and Sakai positions it well for this effort.

Establishing a Global Footprint: Clearly the University of Michigan will need to establish a global footprint to achieve this vision. While it certainly has a strong international reputation in higher education, its current strategy of developing selected partnerships at the institution level will need to be expanded considerably. To some degree this is a "branding" exercise, but more significantly, it will require developing strategic relationships with key international higher education and technology organizations such as OECD, the European University Association, and the LERU universities and their counterparts in Asia.

Building the Necessary Scholarly Foundation for the Effort: To enable such a bold effort, the University will have to establish a strong intellectual foundation of faculty scholarship in areas key to a global knowledge and learning enterprise. Here the University's great strength in the social sciences, along with its many research institutions and professional schools, position it well for such an effort.

Taking Advantage of the University's Decentralized Structure: As we have noted, the University of Michigan is characterized by a highly decentralized organizational structure, in effect, as a loosely coupled adaptive ecosystem. Interestingly enough, this is also similar to the structure of the Internet itself, which has little central control and instead depends upon activity on the edge as it adapts to changes and demands. Hence the unusual structure of the University provides it with an extraordinary capacity to propagate knowledge and learning similar to the Internet itself.

The Public Character of the University of Michigan: The key themes of the 18th Century Enlightenment, the rational distribution of freedom, the universal access to knowledge, and the use of collective experiences stressed that knowledge, learning, and connectivity, were public goods. The public communities of those eras, the salons, seminars, and academies, today have evolved into new forms such as social networks and data clouds. Yet they remain very much public "unions" characterized by "universality", much as the University of Michigan is very much a public institution (although clearly not longer restricted to a state but rather serving the world itself).

Concluding Remarks

The visions we have suggested for the future of the University of Michigan, captured by the terms Universitas, Renaissance, and Enlightenment, become more challenging as we move into the future. Not surprisingly, the roadmaps to these visions for each epoch become less detailed and more uncertain, as does our speculation about the future itself.

This should not be surprising. Such eras of dramatic change have happened many times throughout the history of higher education in America.

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Chapter 9

Tomorrow's World

Although the university has existed as a social institution for almost a millennium, with each historical epoch it has been transformed in very profound ways. The scholasticism of early medieval universities, first appearing in Bologna and Paris, slowly gave way to the humanism of the Renaissance. The graduate universities appearing in early 19th century Germany (von Humboldt's University of Berlin) were animated by the freedom of the Enlightenment and the rigor of the scientific method. The Industrial Revolution in 19th America stimulated the commitment to education of the working class and the public engagement of the land-grant universities. The impact of campus research on national security during WWII and the ensuing Cold War created the paradigm of the contemporary research university during the late 20th century.

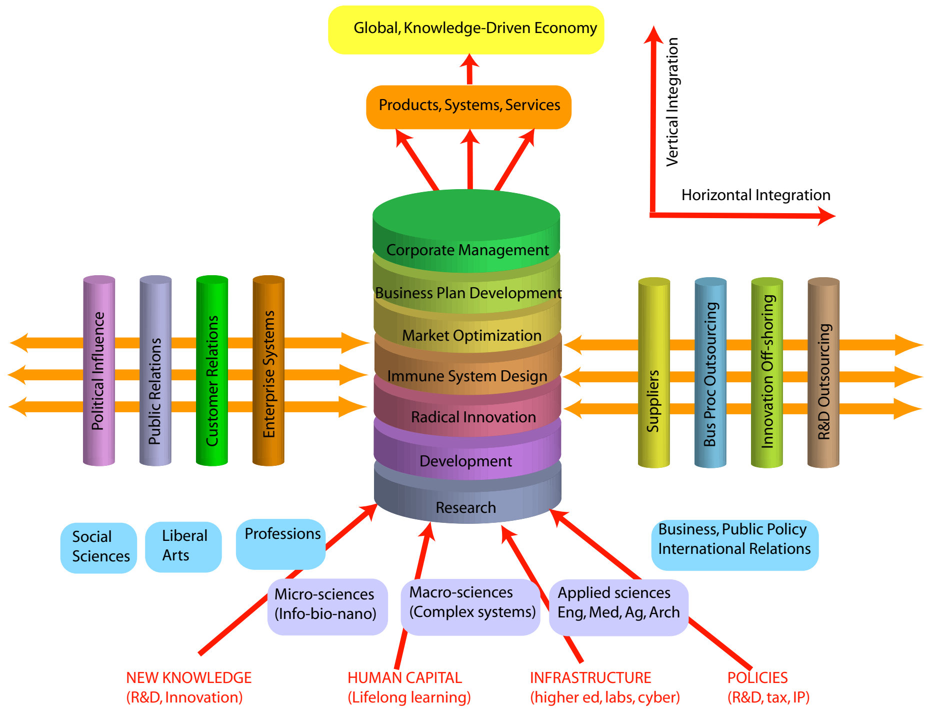
Although the impact of these changes have been assimilated and now seem natural, at the time they involved a profound reassessment of the mission and structure of the university as an institution. But the pace of change in our world is accelerating, with the impact of rapidly evolving technology, changing demographics, and the impact of humankind on our planet. These will pose great challenges to our universities in the next few decades.

The Knowledge Economy

Today we are evolving rapidly into a post-industrial, knowledge-based society as our economies are steadily shifting from material- and labor-intensive products and processes to knowledge-intensive products and services. A radically new system for creating wealth has evolved that depends upon the creation and application of new knowledge. Unlike natural resources, such as iron and oil, which have driven earlier economic transformations, knowledge is inexhaustible. The more it is used, the more it multiplies and expands. But knowledge can be created, absorbed, and applied only by the educated mind. The knowledge economy is demanding new types of learners and creators and new forms of learning and education.

As a survey in *The Economist* put it, "The value of 'intangible' assets–everything from skilled workers to patents to know-how–has ballooned from 20 percent of the value of companies in the S&P 500 to 70 percent today. The proportion of American workers doing jobs that call for complex skills has grown three times as fast as employment in general". (*The Economist*, 2006) Economists estimate that 40 to 60 percent of economic growth each year is due to research and development activity, particularly in American universities. Another 20 percent of the increased resources each year are based upon the rising skill levels of our population. In other words, 60 to 80 percent is really dependent upon higher education in terms of research and development and skills of the labor force. (Augustine, 2005)

Nations are investing heavily and restructuring their economies to create high-skill, high-pay jobs in knowledge-intensive areas such as new technologies, financial services, trade, and professional and technical services. From Paris to San Diego, Bangalore to Shanghai, there is a growing recognition throughout the world that economic prosperity and social well being in a global knowledge-driven economy requires public investment in knowledge resources. That is, regions must create and sustain a highly educated and innovative workforce and the capacity to generate and apply new knowledge, supported through policies and investments in developing human capital, technological innovation, and entrepreneurial skill. Nations both large and small, from Finland to China, are reaping



The way the knowledge economy works.

the benefits of such investments aimed at stimulating and exploiting technological innovation, creating serious competitive challenges to American industry and business both in the conventional marketplace (e.g., automobiles) and through new paradigms such as the off-shoring of knowledge-intensive services (e.g. software development).

In the knowledge economy, the key asset driving corporate value is no longer physical capital or unskilled labor. Instead it is intellectual and human capital. An increasingly utilitarian view of higher education is reflected in public policy. Education is becoming a powerful political force. Just as the space race of the 1960s stimulated major investments in research and education, there are early signs that the skills race of the 21st Century may soon be recognized as the dominant domestic policy issue facing our nation. But there is an important difference here. The space race galvanized public concern and concentrated national attention on educating "the best and brightest," the academically elite of our society. The skills race of the 21st Century will value instead the skills and knowledge of our entire workforce as a key to economic prosperity, national security, and social well-being. The National Governors Association concludes that, "The driving force behind the 21st Century economy is knowledge, and developing human capital is the best way to ensure prosperity." Some governors are even taking the courageous step of proposing tax increases to fund new investments in higher education, research, and innovation. (NGA, 2007)

Perhaps former University of California president Clark Kerr stated it best a half-century ago: "The basic reality for the university is the widespread recognition that new knowledge is the most important factor in economic and social growth, and since that is the university's invisible product, it may be the most powerful single institution in our culture." (Kerr, 1963)

Globalization

Whether through travel and communication, through the arts and culture; or through the internationalization of commerce, capital, and labor; through common environmental concerns, the United States is becoming increasingly linked with the global community. The liberalization of trade and investment policies, along with the revolution in information and communications technologies, has vastly increased the flow of capital, goods, and services, dramatically changing the world and our place in it. Today, globalization determines not only regional prosperity but also national and homeland security. A truly domestic economy has ceased to exist. It is no longer relevant to speak of the health of regional economies or the competitiveness of American industry, because we are no longer self-sufficient or self-sustaining. Markets unleashed by lowering trade barriers are by the instantaneous flows of knowledge, capital, and work. Such markets are creating global enterprises based upon business paradigms such as out-sourcing and off-shoring, a shift from public to private equity investment, and declining identification with or loyalty to national or regional interests.

Our economy and many of our companies are international, spanning the globe and interdependent with other nations and other peoples. Worldwide communication networks have created an international market, not only for conventional products, but also for knowledge professionals, research, and educational services. Market pressures increasingly trump public policy and hence the influence of national governments.

As the report of the National Intelligence Council's 2020 Project has concluded, “The very magnitude and speed of change resulting from a globalizing world–apart from its precise character–will be a defining feature of the world out to 2020. Globalization–growing interconnectedness reflected in the expanded flows of information, technology, capital, goods, services, and people throughout the world will become an overarching mega-trend, a force so ubiquitous that it will substantially shape all other major trends in the world of 2020.” (National Intelligence Council, 2005)

Tom Friedman stresses in his provocative book, *The World is Flat*, “The playing field is being leveled. Some three billion people who were out of the game have walked and often have run onto a level playing field, from China, India, Russia, and Central Europe, from nations with rich educational heritages. The flattening of the world is moving ahead apace, and nothing is going to stop it. What can happen is a decline in our standard of living if more Americans are not empowered and educated to participate in a world where all the knowledge centers are being connected. We have within our society all the ingredients for American individuals to thrive in such a world, but if we squander these ingredients, we will stagnate.” (Friedman, 2005)

Higher education is rapidly globalizing.

In such a global economy, it is critical that regions not only have global reach into markets abroad, but they also have the capacity to harvest new ideas and innovation and to attract talent from around the world. Interestingly enough, higher education becomes a critical asset in providing access to such global markets of commerce and human capital. American universities have long enjoyed a strong international character among their students, faculty, and academic programs. These institutions stand at the center of a worldwide system of learning and scholarship, providing powerful regional magnets to attract new talent, new industry, and new resources from around the world.

Yet, globalization implies a far deeper interconnectedness with the world–economically, politically, and culturally–that goes far beyond simply the international exchange of students, faculty, and ideas and the development of international partnerships among institutions. It requires thoughtful, globally identified, and interdependent citizens. And it requires the mastery of the powerful new communications technologies that are transforming modes of learning, collaboration and expression. The same forces of globalization that challenge our regional economies and cultures will also challenge our educational institutions–and particularly our universities.

Demographics

Demographers project that global population will continue to increase for several more decades, rising to 8.5 billion in 2030, then 9.7 billion in 2050, and 11 billion in 2100. Growth will be limited in developed nations in Europe, Asia, and North American where aging populations and depressed fertility rates are likely to lead to declining populations (with the notable exception of the United States with its unusually high immigration rate). In sharp contrast, developing nations in Asia, Latin American, and particularly Africa (where population is likely to double) will be characterized by young and growing populations with exploding needs for education. Unless developed nations step forward and help address this crisis, billions of people in coming generations will be denied the education so necessary to compete in, and survive in, the knowledge economy. The resulting despair and hopelessness among the young will feed the terrorism that so threatens our world today.

America's population is changing rapidly. One of the most significant demographic trends is the aging of our population. The baby boomers are entering retirement, and the number of young adults is declining. In the U.S., there are already more people over the age of sixty-five than teenagers in this nation, and this situation will continue for decades to come. More generally, the populations of most developed nations in North America, Europe, and Asia are also aging rapidly, where over the next decade, the percentage of the population over 60 will grow to 30% to 40%. Half of the world's population today lives in countries where fertility rates are not sufficient to replace their current populations, e.g. the average fertility rate in the EU has dropped to 1.45, below the 2.1 necessary for a stable population. Aging populations, out-migration, and shrinking workforces are seriously challenging the productivity of developed economies throughout Europe and Asia. (National Intelligence Council, 2004; Baumgardt, 2006)

Yet here the United States stands apart because of a second and equally profound demographic trend: immigration. As it has been so many times in its past, America is once again becoming a highly diverse nation of immigrants, benefiting immensely from their energy, talents, and hope. Such population mobility is rapidly changing the ethnic character of our nation. In fact, over the past decade, immigration from Latin America and Asia contributed 53% of the growth in the United States population, exceeding that provided by births. (National Information Center, 2006) Immigration is expected to drive continued growth in the U.S. population from 300 million today to over 450 million by 2050, augmenting our aging population and stimulating productivity with new and young workers.

Because America is characterized by great diversity in geography, regional economics, and cultures, immigrants have an incredible array of choice. (The Economist, 2009) The proportion of Americans who are foreign-born, at 13%, is higher than the rich-country average of 8.4%. In absolute terms, the gulf is much wider. America's foreign-born population of 38 million is nearly four times larger than those of Russia or Germany, the nearest contenders. It dwarfs the number of immigrants in Japan (below 2 million) or China (under 1 million).

Immigration is vital to growing a regional economy. Although one usually thinks of immigrants taking low-skill jobs in poorly paid services, manufacturing, and agriculture, in reality much of the immigrant population is very high skill. Today's immigrants tend to fall into two classes. At the top are scientists, doctors, engineers, and managers largely from Asia. At the bottom are the laborers, often poorly educated and largely Hispanic, who perform the very low skill jobs that keep our society functioning. Historically, immigrants and multinational populations have been the greatest contributors to urban population and growth, including growth in major U.S. cities over the past 20 years. They are the source of new enterprises, and they stimulate the innovative and entrepreneurial culture that creates diverse, multi-ethnic, urban communities that are attractive to talented, educated, and young residents. (Longworth, 2008)

Yet even without immigration the minority population in the United States will continue to grow for decades to come, rising from 35% today to 42% by 2050. (Frey, 2010; Brownstein 2010) Minorities now comprise 44% of the children under the age of 18, the "Millennial" generation of students now entering our colleges. By 2023, minorities will comprise the majority of American children (and eventually our population).

The increasing diversity of the American population with respect to race, ethnicity, gender and national origin is both one of our greatest strengths and one of our most serious challenges as a nation. A diverse population gives us great vitality. However, the challenge of increasing diversity is complicated by social and economic factors. Far from evolving toward one America, our society continues to be hindered by the segregation and non-assimilation of minority cultures, as well as a backlash against long-accepted programs designed to achieve social equity (e.g., affirmative action in college admissions). Furthermore, since most current immigrants are arriving from developing regions with weak educational capacity, new pressures have been placed on U.S. educational systems for the remedial education of large numbers of non-English speaking students.

The full participation of currently underrepresented minorities will be of increasing concern as we strive to realize our commitment to equity and social justice. Yet the achievement of this objective also will be the key to the future strength and prosperity of America, since our nation cannot afford to waste the human talent presented by its minority and immigrant populations. If we do not create a nation that mobilizes the talents of all of our citizens, we are destined for a diminished role in the global community and increased social turbulence. Most tragically, we will have failed to fulfill the promise of democracy upon which this nation was founded.

But there is another important demographic trend: the lengthening of human lifespan driven by the progress of biomedical science, particularly in developed nation. Those in today's Millennial generation (those born between 1980 and 1995) have an expected lifespan into their 90s, while today's young children have a 50% chance to live to 100 or longer. (Gratton, 2016) While certainly encouraging from a public health perspective, the downside is the fact that even prosperous societies will simply be unable to afford supporting decades of retirement beyond the age of 70. Longer lives will require more years of work. Yet it is also clear that an education received in one's youth will likely not be sufficient to sustain their employment 50 years later. Hence lifelong education and continually retraining will become essential, and this will pose new challenges to higher education. (The Economist, Lifelong Learning, 2017)

Technological Change

The technologies of today, cyberinfrastructure, big data, artificial intelligence, clouds, and soon quantum computing have the disruptive feature that they continue to grow in power at exponential rates, increasing 100 to 1,000 fold each decade. (Kelly, 2016) The rapid evolution of digital technology not only accelerates conventional economic activity, but it creates entirely new ventures such as social media, virtual and augmented reality, intelligent agents (Siri and Alexa), and sophisticated data management and access. (The Economist, Technology Quarterly, 2017) Furthermore as the technology continues to evolve, so too do the ambitions of those organizations that exploit it such as Google (to make available all the world's knowledge to all people), Facebook (to connect all the people of the world), and Amazon (an everything, everywhere store).

In particular, the fundamental intellectual activities of discovery and learning enabling the knowledge economy are being transformed by the rapid evolution of information and communications technology. Although many technologies have transformed the course of human history, the pace and impact of digital information technology is unprecedented. In little more than half a century, we have moved from mammoth computer temples with the compute power of a digital wristwatch to an ecosystem of billions of microelectronic devices, linked together at nearly the speed of light, executing critical complex programs with astronomical quantities of data. Rapidly evolving digital technology has played a particularly important role in expanding our capacity to generate, distribute, and apply knowledge. It has become an indispensable platform for discovery, innovation, and learning. Information and communications services are increasingly delivered as a utility, much like electricity, from remote data centers and networks. Both hardware and software are now moving into massive network "clouds" managed by providers, such as Microsoft, Google, and Amazon. They provide not only global connectivity to organizations (e.g., corporations, governments, and universities) but also to individuals in rapidly changing forms, such as instant messaging, televideo, crowd sourcing, and affinity communities.

As Brynjolfsson and McAfee suggest, information technology is both quantitatively and qualitatively different in character since it evolves exponentially (Moore's Law), is easily and cheaply reproduced because of its digital character, and is highly recombinant through networks and ubiquitous access. (Brynjolfsson, 2013) More generally it is becoming increasingly clear that we are approaching an inflection point in the potential of rapidly evolving information and communications technology to transform how the scientific and engineering enterprise does knowledge work, the nature of the problems it undertakes, and the broadening of those able to participate in research activities. It is becoming increasingly clear that we are approaching an inflection point in the potential of these technologies to radically transform knowledge work.

Beyond acknowledging the extraordinary and unrelenting pace of such exponentially evolving technologies, it is equally important to recognize that they are disruptive in nature. Their impact on social institutions such as corporations, governments, and learning institutions is profound, rapid, and quite unpredictable. While such technologies have had great positive impact on our lives, they also threaten our current activities. For example, increasing power of AI clouds, the Internet of Things, and other automation technologies are transforming our economy (what Schwab calls the Fourth Industrial Revolution), (Schwab, 2015) eliminating more routine jobs in fields such as construction, manufacturing, and services. More generally there is a strong concentration of wealth driven by the new technologies, since the return on capital and technology is greater than for labor, leading to not only jobless economic growth but also increasing income disparities. In fact, some suggest that in a future that may have only 20% of today's jobs, the real challenge will become how to create meaningful lives in a world with rapidly increasing machine intelligence. (The Economist, Special Report on Artificial Intelligence, 2016) With our current education system, most citizens will not have the skills for the new jobs. Of course, we might argue that there will always likely to be some jobs that can be performed better by humans than AI systems, particularly those involving empathy or social interaction. In fact, one might suggest that such "human traits" should be given a much higher priority in learning organizations such as universities.

IBM Summit supercomputer
(Oak Ridge National Laboratory)

Today, a rapidly changing world demands a new level of knowledge, skills, and abilities on the part of our citizens. Just as in earlier critical moments in history when our prosperity and security was achieved through broadening and enhancing educational opportunity, it is time once again to seek a bold expansion of educational opportunity. But this time we should set as the goal providing all citizens with universal access to lifelong learning opportunities, thereby enabling participation in a world both illuminated and driven by knowledge and learning.

Creativity, Communication, and Convergence

The professions that have dominated the late 20th Century—and to some degree, the contemporary university—have been those which manipulate and rearrange knowledge and wealth rather than create it, professions such as law, business, accounting, and politics. Yet, it is becoming increasingly clear that the driving intellectual activity of the 21st Century will be the act of creation itself.

We now have the capacity to create new objects literally atom by atom. With new methods in molecular biology such as CRISPR/cas9 and gene drive, we can not only precisely modify the DNA code for a living organism, but we can actually cause it to propagate through a species to change future generations (a frightening thought when human gene editing is considered). (Baltimore, 2015) The dramatic pace of evolution of information technology shows no sign of slowing, continuing to advance in power from 100 to 1000 fold a decade, enabling not only new forms of analysis such as augmenting the traditional tools of experiment and theory with the sophisticated tools of data analysis (big data). Indeed, the tools of artificial intelligence not only are rapidly progressing, but they have stimulated fears of eventual sentient behavior of machines.

Already we are seeing the spontaneous emergence of new forms of creative activities, e.g., the "maker" fairs providing opportunities to showcase forms of artistic, recreational, and commercial activity; the use of "additive manufacturing" to build new products and processes atomic layer by atomic layer; and the growing use of the "app" culture to empower an immense marketplace of small software development companies. In fact, some suggest that our civilization may experience a renaissance-like awakening of creative activities in the 21st century similar to that occurring in 16th century Europe.

The determining characteristic of the university of the 21st Century may be a shift in intellectual focus, from the preservation or transmission of knowledge, to the process of creativity itself. If so, then the vision for the university of 2030 should stress characteristics such as creativity, innovation, ingenuity and invention, and entrepreneurial zeal. But here lies a great challenge. While universities are experienced in teaching the skills of analysis, we have far less understanding of the intellectual activities associated with creativity. In fact, the current disciplinary culture of our campuses sometimes discriminates against those who are truly creative and do not fit well into our stereotypes of students and faculty.

Yet another feature of our information rich society is our capacity for communication. The internet and related technologies such as smartphones and cloud computing make it cheap and easy not only to communicate but also to collect, store, and analyze immense quantities of information. But while facilitating communication and communities, such technology also has its downside. Always on, always used communication consumes the attention of individuals. Indeed, this attention is the valuable commodity needed by advertisers that actually funds these communications networks.

Finally, the very structure of knowledge is continuing to shift as fields such as biology, physics, mathematics, and the social sciences are converging. (Sharp, 2014) Today physicists and engineers have as much impact on the evolution of biological science as biologists do on chemistry and computer technology (e.g., the deep learning algorithms derived from neural networks). The emergence of convergence (or consilience, as E.O. Wilson would term it) is challenging the disciplinary fragmentation of the University into departments, schools, and colleges.

Any vision proposed for the university's third century must consider the extraordinary changes and uncertainties of a future driven by exponentially evolving information and communications technology. The extraordinary connectivity provided by the Internet already links together the majority of the world's population. To this, one can add the emerging capacity to capture and distribute the accumulated knowledge of our civilization in digital form and provide opportunities for learning through new paradigms such as MOOCs and AI cognitive tutors. This suggests the possible emergence of a new global society no longer constrained by space, time, monopoly, or archaic laws and instead even more dependent upon the generation of new knowledge and the education of world citizens. In such an era of rapid change, it has become the responsibility of democratic societies to provide their citizens with the learning opportunities they need throughout their lives, at costs they can afford, as a right rather than a privilege. (Germano, 2010)

Social and Political Change

Even as our world becomes increasingly dependent upon knowledge, the very technology that is key to creating, archiving, and making available knowledge is ironically being used to attack and undermine it. In the Trump era, social media not only has become a powerful tool of American politics, but it provides the capacity to distort knowledge and truth, the "alt-truth" phenomenon that allow a tidal wave of anger built on the social media Twitter to not only win a presidential election but to build a powerful, almost mythological force capable of challenging the evidence-based truth critical to a democracy. (Brooks, 2017) While counterforces such as Wikipedia and digital libraries were thought of as power technologies capable of distributing facts and truth, the worry today is that the alt-truth deluge from social media may in fact be eroding American democracy. (*The Economist*, Technology and Politics, 2016)

Xenohobic and racist energy creates a hostile electorate that is not only unwilling to accept truth established by evidence, but has largely abandoned the scientific method (with only 25% of Americans now expressing confidence in scientific discovery). (Miller, 2016) Both parents and young people are beginning to question the value of higher education.

Policy makers, determined to serve their "populist" constituencies, are erecting barriers to higher education based on race and class. Nearly two decades into our new century, there are unmistakable signs that America's fabled social mobility is in trouble—perhaps even in serious trouble. "We are faced with a challenge to liberalism by populists who are challenging the ideas of freedom, equality, human rights, representative democracy and globalization with our current post-truth age in which expertise on matters such as climate change is rubbished and institutions are deemed untrustworthy."(Gitlin, 2017)

Global Sustainability

While history has always been characterized by periods of both change and stability – war and peace, intellectual progress and decadence, economic prosperity and contraction – today the pace and magnitude of such changes have intensified, driven by the powerful forces of globalization, changing demographics, rapidly evolving technologies and the expanded flows of information, technology, capital, goods, services and people worldwide. Economies are pushing the human exploitation of the Earth's environment to the limits; the military capacity of the great powers could destroy the world population many times over, business corporations have become so large that they can influence national policies, the financial sector has become so complex and unstable that it has the capacity to trigger global economic catastrophes in an instant, and corrupted regimes leading to failed states still appear in all parts of the world. Many believe that the impact of human activities, ever more intense, globally distributed and interconnected, threatens the very sustainability of humankind on Earth, at least in terms that we currently understand and enjoy.

While the fruits of development and modernity are indisputable, the negative consequences of these recent developments appear to be increasingly serious. For example, there is compelling evidence that the growing population and invasive activities of humankind are now altering the fragile balance of our planet. The concerns are multiplying in number and intensifying in severity: the destruction of forests, wetlands and other natural habitats by human activities, the extinction of millions of species and the loss of biodiversity; the buildup of greenhouse gases and their impact on global climates; the pollution of our air, water and land. We must find new ways to provide for a human society that presently has outstripped the limits of global sustainability.

So, too, the magnitude, complexity, and interdependence (not to mention accountability) of business practices, financial institutions, markets and government policies now threaten the stability of the global economy, as evidenced by the impact of complex financial instruments and questionable market incentives in triggering the collapse of the global financial markets that led to the "Great Recession" of 2008-2009. Again, the sustainability of current business practices, government policies and public priorities must be questioned.

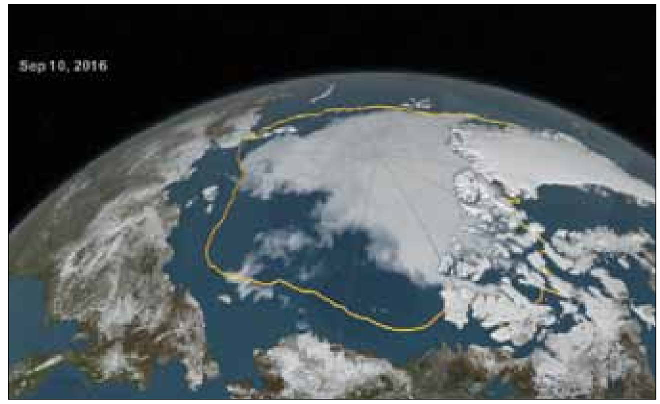
Of comparable concern are the widening gaps in prosperity, health and quality of life characterizing developed, developing and underdeveloped regions. To be sure, there are some signs of optimism: a slowing population growth that may stabilize during the 21st century, technological advances such as the "green revolution" have fed much of the world, and the rapid growth of developing economies in Asia and Latin America. Yet it is estimated that one-sixth of the world's population still live in extreme poverty, suffering from diseases such as malaria, tuberculosis, AIDS, diarrhea and others that prey on bodies weakened by chronic hunger, claiming more than 20,000 lives daily. These global needs can only be addressed by the commitment of developed nations and the implementation of technology to alleviate poverty and disease.

The world's research universities have for many years been actively addressing many of the important issues associated with global sustainability. The "green revolution" resulting from university programs in agricultural science has lifted a substantial portion of the world's population from the ravages of extreme poverty. University scientists were the first to alert the world to the impact of human activities on the environment and climate, e.g., the impact of CFCs on atmospheric ozone depletion; the destruction of forests, wetlands and other natural habitats by human activities leading to the extinction of millions of biological species and the loss of biodiversity; and the buildup of greenhouse gases, such as carbon dioxide and their impact on the global climate. University biomedical research has been key to dealing with global health challenges, ranging from malaria to Nile virus to AIDS, and the international character of research universities, characterized by international programs, collaboration and exchanges of students and faculty provide them with a unique global perspective.

Global Poverty and Health

During the past several decades, technological advances such as the "green revolution" have lifted a substantial portion of the world's population from the ravages of poverty. In fact, some nations once burdened by overpopulation and great poverty such as India and China, now are viewed as economic leaders in the 21st century. Yet today there remain substantial and widening differences in the prosperity and quality of life of developed, developing, and underdeveloped regions, e.g., differences between the North and South Hemisphere and within many nations (including the deplorable level of poverty tolerated in our own country).

It is estimated that roughly one-sixth of the world's population, 1.5 billion people, still live in extreme poverty-defined by Jeffrey Sachs as "being so poor you could die tomorrow", mostly in sub-Saharan Africa, parts of South America, and much of central Asia. Put in even starker terms, "More than 8 million people



Increasing signs of global climate change.

around the world die each year because they are too poor to stay alive. (Sachs, 2004)

These massive global needs can only be addressed by both the commitment of developed nations and the implementation of technology to alleviate poverty and disease. The United States faces a particular challenge and responsibility in this regard. With just 5% of the world's people, we control 25% of its wealth and produce 25% to 30% of its pollution. It is remarkable that the richest nation on earth is the lowest per capita donor of international development assistance of any industrialized country. As the noted biologist Peter Raven observes, "The United States is a small part of a very large, poor, and rapidly changing world, and we, along with everyone else, must do a better job. Globalization appears to have become an irresistible force, but we must make it participatory and humane to alleviate the suffering of the world's poorest people and the effective disenfranchisement of many of its nations". (Raven, 2003)

Still More Possibilities

There are other possibilities that might be considered for the longer-term future. Balancing population growth in some parts of the world might be new pandemics, such as a new avian flu virus or air-borne Ebola, which appear out of nowhere to ravage our species. The growing divide between rich and poor, the developed nations and the third world, the North and South hemispheres, could drive even more serious social unrest and terrorism, perhaps armed with even more terrifying weapons.

Then, too, the unrelenting–indeed, accelerating pace

Perhaps mankiind will launch and era
of space exploration...to Mars and beyond

Or perhaps we will encounter a technological
singularity such as artificial intelligence!

of technology could benefit humankind, extending our lifespan and quality of life (although perhaps aggravating population growth in the process), meeting the world's needs for food and shelter and perhaps even energy, and enabling vastly new forms of communication, transportation, and social interaction. Perhaps we will rekindle our species' fundamental quest for exploration and expansion by resuming human spaceflight and eventually colonizing our solar system and beyond.

Sustained progress in the development of new technologies has been the central feature of the past century and is likely to be even more so in the century ahead. But technology will also present new challenges that almost seem taken from the pages of science fiction. Clearly if digital technology continues to evolve at its current pace for the next decade, creating machines a thousand, a million, a billion times more powerful than those which are so dominating our world today, then phenomena such as the emergence of machine consciousness and intelligence become very real possibilities during this century.

John von Neumann once speculated that "the ever accelerating progress of technology and changes in the mode of human life gives the appearance of approaching some essential singularity in the history of the race beyond which human affairs, as we know them, could not continue." The acceleration of technological progress has been the central feature of the past century and is likely to be even more so in the century ahead. Some futurists have even argued that we are on the edge of change comparable to the rise of human life on Earth. The precise cause of this change is the imminent creation by technology of entities with greater than human intelligence. For example, as digital technology continues to increase in power a thousand-fold each decade, at some point computers (or, more likely, large computer networks) might "awaken" with superhuman intelligence. Or biological science may provide the means to improve natural human intellect. (Kurzweil, 2005)

When greater-than-human intelligence drives technological evolution, that progress will be much more rapid, including possibly the creation of still more intelligent entities, on a still shorter timescale. To use Von Neumann's terminology, at such a technological "singularity", our old models must be discarded and a new reality appears, perhaps beyond our comprehension. We probably cannot prevent the singularity, since driven as it is by humankind's natural competitiveness and the possibilities inherent in technology, we are likely to be the initiators. But we have the freedom to establish initial conditions, make things happen in ways that are less inimical than others–if we have the wisdom to do so. (Kurzweil, 2005)

Clearly phenomena such as machine consciousness, contact by extraterrestrial intelligence, or cosmic extinction from a wandering asteroid are possibilities for our civilization, but just as clearly they should neither dominate our attention nor our near-term actions. Indeed, the most effective way to prepare for such unanticipated events is to make certain that our descendants are equipped with education and skills of the highest possible quality.

As we look even further into an unknowable future, the possibilities and uncertainties become even more challenging. Attempting to predict the future is always a hazardous activity. We generally overestimate change in the near term and underestimate it for the longer term, in part because we usually tend to extrapolate what we know today into a future that becomes increasingly beyond our imagination. It is very difficult to peer over the horizon.

Universities are crucial in predicting, understanding, and addressing these possibilities. They are needed to produce new generations of thoughtful, interdependent, and globally identified citizens. To quote from the 1999 Glion Declaration:

> "The daunting complexity of the challenges that confront us would be overwhelming if we were to depend only on existing knowedge, traditional resources, and conventional approaches. But universities have the capacity to remove that dependence by the innovations they create. Universities exist to liberate the unlimited creativity of the human species and to celebrate the unbounded resilience of the human spirit. In a world of foreboding problems and looming threats, it is the high privilege of universities to nurture that creativity, to rekindle that resilience, and so provide hope for all of Earth's people." (Rhodes, 2009)

How Do We Lead Our Universities into the Future?

As many leaders in higher education have come to realize, our changing environment requires a far more strategic approach to the evolution of our institutions at all levels. It is critical for higher education to give thoughtful attention to the design of institutional processes for planning, management, leadership, and governance. The ability of universities to adapt successfully to the profound changes occurring in our society will depend a great deal on the institution's collective ability to develop and execute appropriate strategies. Key is the recognition that in a rapidly changing environment, it is important to develop a planning process that is not only capable of adapting to changing conditions, but to some degree capable of modifying the environment in which the university will find itself in the decades ahead. We must seek a progressive, flexible, and adaptive process, capable of responding to a dynamic environment and an uncertain—indeed, unknowable—future.

There are always opportunities to control constraints—and the future—if one takes a proactive approach. Universities are rarely playing in a zero-sum game. Instead, they may have the opportunity to increase (or decrease) resources with appropriate (or inappropriate) strategies. The university is never a closed system. Put in more engineering terms, any complex system can be designed in such a way as to be less sensitive to initial and/or boundary conditions. A successful strategic planning process is highly iterative in nature. While the vision remains fixed, the goals, objectives, actions, and tactics evolve with progress and experience. During a period of rapid, unpredictable change, the specific plan chosen at a given instant is of far less importance than the planning process itself. Put another way, one seeks an "adaptive" planning process appropriate for a rapidly changing environment and a loosely coupled adaptive system such as a university. (Duderstadt, 2000)

In an institution characterized by the size and complexity of the contemporary research university, it is usually not appropriate (or possible) to manage centrally many processes or activities. One can, however, establish institutional priorities and goals and institute a process that encourages local management toward these objectives. To achieve institutional goals, processes can be launched throughout the institution aimed at strategic planning consistent with institutional goals, but with management authority residing at the local level. One seeks an approach with accurate central information support and strong strategic direction.

Institutions all too frequently chose a timid course of incremental, reactive change because they view a more strategically-driven transformation process as too risky. They are worried about making a mistake, about heading in the wrong direction or failing. While they are aware that this incremental approach can occasionally miss an opportunity, many mature organizations such as universities would prefer the risk of missed opportunity to the danger of heading into the unknown.

But, today, incremental change based on traditional, well-understood paradigms may be the most dangerous course of all, because those paradigms may simply not be adequate to adapt to a future of change. If the status quo is no longer an option, if the existing paradigms are no longer viable, then transformation becomes the wisest course.

Universities have always managed the balance between preserving and propagating the fundamental knowledge sustaining our cultures and civilizations and not only adapting to but actually creating the paradigm shifts that drive change. But the time scales characterizing these roles are becoming ever shorter. The centuries characterizing social transitions such as scholasticism to humanism and enlightenment contracted to decades for the industrial revolution and globalization and now have collapsed even further to within a generation or less for the age of knowledge as the technologies of our times now evolve exponentially. Put another way, during the transition from Generation X to the Millennials, info-, bio-, and nano-technology have increased in power a million-fold. They will likely do so yet again with Generation Z.

The capacity for intellectual change and renewal has become increasingly important to us as individuals and to our institutions. Our challenge, as an institution, and as a faculty, is to work together to provide an environment in which such change is regarded, not as threatening but rather as an exhilarating opportunity to conduct teaching and scholarship of even higher quality and impact on our society.

To succeed, we strive for a more flexible culture, one more accepting of occasional failure as the unavoidable corollary to any ambitious effort. We must learn to adapt quickly while retaining the values and goals that give us a sense of mission and community. Many view the current rigid and hierarchical structure of the university as obsolete. To advance, we must discover ways to draw upon the unique and vibrant creativity of every member of our community.

It is often scary and difficult to let go of old and comfortable roles, to open ourselves to new possibilities and ways of being. Yet change brings with it the possibility of deeper connections to our students and the potential for serving a much broader range of our society. Growth, both for an institution and for the individuals that comprise it, can come only with a step into the unknown.

Our challenge is to tap the great source of creativity and energy of outstanding faculty, students, and staff, working at the grassroots level of the academic enterprise of the University in a way that preserves our fundamental mission and values. We need to continue to encourage our tradition of natural evolution, which has been so successful in responding to a changing world, but do so with greater strategic intent. We must also develop a greater capacity to redirect our resources toward our highest priorities. Rather than allowing the university to continue to evolve as an unconstrained, transactional, entrepreneurial culture, we need to guide this process in such a way as to preserve our core missions, characteristics, and values.

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Chapter 10

A Roadmap for Michigan's Third Century

It is hard for those of us who have spent much of our lives as academics to look at the university, with its traditions and obvious social value, and accept the possibility that it soon might change in dramatic ways. Although the university has existed as a social institution for almost a millennium, with each historical epoch it has been transformed in very profound ways.

The scholasticism of early medieval universities, first appearing in Bologna and Paris, slowly gave way to the humanism of the Renaissance. The graduate universities appearing in early 19th century Germany (von Humboldt's University of Berlin) were animated by the freedom of the Enlightenment and the rigor of the scientific method. The Industrial Revolution in 19th America stimulated the commitment to education of the working class and the public engagement of the land-grant universities. The impact of campus research on national security during WWII and the ensuing Cold War created the paradigm of the contemporary research university during the late 20th century.

Although the impact of these changes have been assimilated and now seem natural, at the time they involved a profound reassessment of the mission and structure of the university as an institution. But the pace of change in our world is accelerating, with the impact of rapidly evolving technology, changing demographics, and the impact of humankind on our planet. These will pose great challenges to our universities in the next few decades.

A Roadmap for Michigan's Third Century

We now turn to the development of a strategic roadmap for the University of Michigan as it enters its third century. This is designed as an evolving framework of actions aimed to guide the University through its vision trilogy of *Universitas, Renaissance, and Enlightenment*.

Earlier chapters in this report have provided the foundation for this effort, scanning the technology environment in which the University now finds itself, assessing our current assets and challenges, and proposing a vision for our future, based upon our values, characteristics, and opportunities. In this chapter we begin by suggesting a framework for the recommendations that will comprise the University's roadmap for the third century, drawing from the experience of earlier strategic planning efforts both at Michigan and other venues. Key in this framework effort is the establishment of goals involving the most critical assets of the university: people, resources, culture, and the capacity for change. These will shape the subsequent recommendations of the roadmap.

The roadmap itself will be structured into three time-frames or "event horizons" associated with each element of the vision proposed in Chapter 6: *Unversitas*, (its current character); *Renaissance*, (launched over the next several years but guiding the University as it moves into its third century; and *Enlightenment* phase, launched over the next decade and lasting well into the University's third century.

Clearly, the various phases of the roadmap associated with the trilogy of visions are interdependent. In the sense one might think of the roadmap as a path through a series of mountain ranges. Until one successfully climbs the first range, it is impossible to see far enough to set the course for climbing the next. Hence in the next chapter, we will also suggest a series of plans, processes, and tactics for keeping the roadmap effort on track as we move from one range to the next.

Always Begin with the Basics

So how to begin? How does one grapple with the many issues and concerns swirling about higher education in general, and the University of Michigan in particular, to chart a course toward the visions for its third century? Let us suggest the following framework drawn from experience in higher education and other contexts.

It is critical to first determine those key roles and values of the institution that must be protected and preserved in the years ahead. While it is important to engage the university community in an ongoing discussion of these guiding principles, one might begin with the canonical roles of the research university, namely education of the young, preservation of culture, basic research and scholarship, serving as a critic of society, and so forth. The starting point for a discussion of fundamental values could also be drawn from the academy, e.g., academic freedom, a rational spirit of inquiry, a community of scholars, a commitment to excellence, and shared governance.

The next phase would be to identify actions to help the university better understand and respond to the changing needs of the society we serve rather than defending and perpetuating an obsolete past. Key here is listening carefully to our stakeholders and patrons to learn and understand their changing needs, expectations, and perceptions of higher education, along with the forces driving change.

Since roadmapping is very much an exercise in institutional change, it is important to prepare the academy for change and competition, e.g., by removing unnecessary constraints, linking accountability with privilege, redefining tenure as the protection of academic freedom rather than lifetime employment security, etc. This includes developing a tolerance for strong leadership and instituting the best practices of governance, leadership, and management.

When the road ahead becomes uncertain, experimentation becomes an important element of the planning framework. The university should strongly encourage experimentation with new paradigms of learning, research, and service, harvesting the best ideas

The Fundamental Goals

We propose several simply stated goals to provide a foundation for the roadmap that will guide the University toward the vision for its third century:

Goal 1: People

To attract, retain, support, and empower exceptional students, faculty, and staff.

Goal 2: Resources

To provide these people with the resources and environment necessary to push to the limits of their abilities and their dreams.

Goal 3: Culture

To build a University culture and spirit that values adventure, excitement, risk-taking, leadership, excellence, diversity, caring, concern, and community.

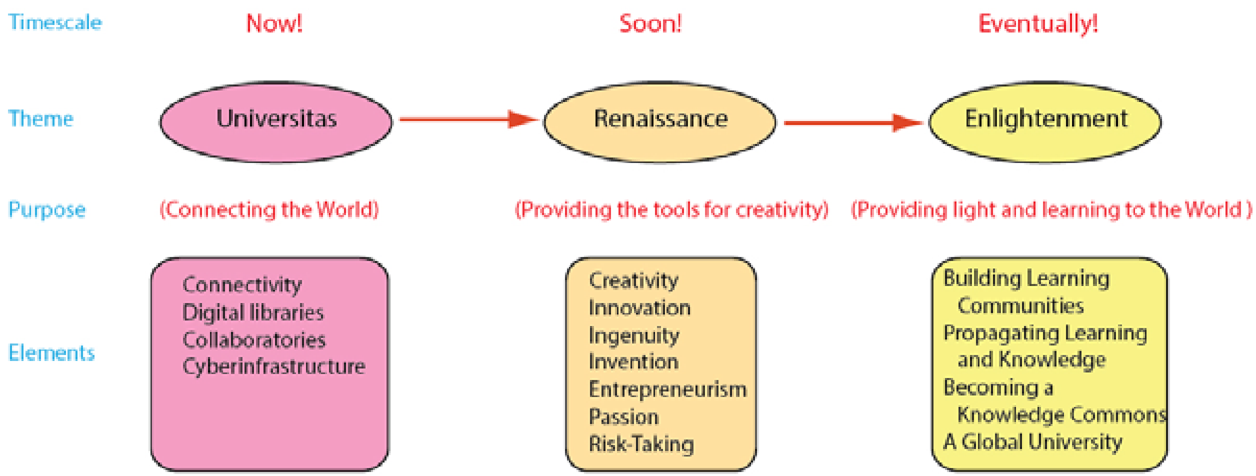
Goal 4: The Capacity for Change

To develop the flexibility, the ability to focus resources necessary to serve a changing society and a changing world.

These four concrete goals have profound implications, and each will be deceptively challenging to execute. While we have always sought to attract high-quality students and faculty to the University, we tend to recruit those who conform to more conventional measures of excellence. If we are to seek "paradigm breakers," then other criteria such as creativity, intellectual span, and the ability to lead become important.

We need, as well, to acquire the resources to sustain excellence, a challenge at a time when public support is dwindling. Yet, this goal also suggests that we need to focus resources on our most creative people and programs. And we need to acquire the flexibility in resource allocation to respond to new opportunities and initiatives.

While most people and institutions would agree with the values set out in the third goal of cultural change, many would not have assigned such a high priority to striving for adventure, excitement, and risk-



taking. However, if the University is to sustain its saga as a pathfinder and trailblazer in defining the nature of higher education in the century ahead, this type of culture will be essential.

Developing the capacity for change, while an obvious goal, will also be both challenging and controversial. We need to discard the status quo as a viable option, challenge existing premises, policies, and mindsets, and empower our best people to drive the evolution—or revolution—of the University.

This capacity for change, for renewal, is the key objective that we must strive to achieve in the years ahead—a capacity that will allow us to transform ourselves once again as the university has done so many times in the past, to become an institution capable of serving a changing society and a changing world. Such institutional transformation has become commonplace in other sectors of our society. We frequently hear about companies "restructuring" themselves to respond to rapidly changing markets. Government is also challenged to transform itself to be more responsive and accountable to the society that supports it. Yet transformation for the university is necessarily more challenging, since our various missions and our diverse array of constituencies give us a complexity far beyond that encountered in business or government. It must be approached strategically rather than reactively, with a deep understanding of the role and character of our institutions, their important traditions and values from the past, and a clear and compelling vision for their future.

The Roadmap Begining with *Universitas*

For the near term our vision of *Universitas* suggests the University of Michigan should focus on understanding, assessing, and embracing those values and characteristics that have played such an important role throughout its history:

Academic quality
Academic priority
Diversity
Public Purpose
Spirit
Leadership:
The Michigan Saga as pathfinder and trailblazer

Renewing our effort (or restoring our commitment if necessary) to achieve these characteristics seems obvious. Yet it is nevertheless this current vision that the University should set out as today's most important challenge. We suggest the following elements of a roadmap to achieve this near term vision:

- What is a public university in the knowledge-driven global society of the 21st century? What is its public purpose? Whom does it serve? Who are its stakeholders and patrons?

- What are the role and responsibility of the flagship state university in a world characterized by increasing connectivity and mobility of people and knowledge?
- What is the appropriate balance among undergraduate, graduate, and professional education in a comprehensive research university, and how should these be interrelated?

Here a caution is appropriate: While such milestones such as the University's Bicentennial in 2017 presented an opportunity for other agendas such as fund-raising or marketing the institution, it would be tragic if these ancillary activities were to overwhelm a more substantive celebration of the true academic character of the University and a consideration of its future.

Better Engagement of Faculty in University History Projects: It is very important to provide strong encouragement to senior faculty to participate in University history activities, since many have very important and unique perspectives through their own experiences. To this end:

- Faculty History and Tradition Committees should be created in each school or college.
- The efforts of senior and emeritus faculty to share their own contributions to the history of the University should be strongly encouraged. In particular, funds should be created at both the University and school or college level to provide subventions for such faculty history projects (books, archives, etc.)
- The University of Michigan Press should consider creating a special series of historical publications by Michigan faculty (similar to those at several leading private universities).

Restoring a Sense of Public Purpose: The University has drifted too far from its early public purpose of providing "an uncommon education for the common man". In fairness, much of this has been a consequence of eroding state support that has forced the University to develop alternative revenue streams, e.g., increasing the enrollments of out-of-state students paying higher tuition, promoting "premium" services for those activities with strong market appeal (e.g., college athletics, student housing, parking). But these decisions have had a significant impact on the University's "public" character, as the fraction of the student body from low-income backgrounds has declined and community participation in activities such as Michigan football and theatrical productions (e.g., University Musical Society) has become increasingly rarefied with skyrocketing ticket prices.

Reflecting upon the Michigan saga

As it has throughout its history, the University needs to acknowledge its public character and be attentive to the needs of the society it serves. New financial paradigms will be necessary to enable the University to achieve a student socioeconomic balance that better reflects society. It is also clear that the University needs to take a more strategic approach toward public service and engagement. In the years ahead, the institution will be called upon to provide a broad array of public services consistent with our public mission. Developing the capacity to assess such opportunities and responsibilities and then to make rational decisions about which to accept is crucial. We need to develop the capacity to say "no" when a societal request does not align well with our academic mission or could better be performed by other institutions.

Strengthening the University's Commitment to Diversity: The University needs to reaffirm and broaden its commitment to creating a institution characterized by great diversity. As with biological organisms or ecosystems, the diversity of the University may well be the key characteristic that will allow it to flourish

Recommitting Michigan to Diversity


Recapturing the Michigan Spirit

in a rapidly changing environment. Diversity goes far beyond racial and ethnic representation to include almost every aspect of the human condition: race, gender, nationality, economic circumstances, and beliefs. The challenge is to build an institution in which people of different backgrounds, ethnicities, cultures, and beliefs come together in a spirit of respect and tolerance for these differences while working together to learn and to serve society.

During the 1990s the University made great progress in achieving diversity through major strategic efforts such as the Michigan Mandate, the Michigan Agenda for Women, and other initiatives aimed at responding to the increasing diversity of our society. Yet today, much of this progress has been lost. Undergraduate enrollments of underrepresented minorities have dropped to half their previous levels. Several of the University's professional schools (notably Law, Business, and Medicine) have experienced ever more dramatic declines in minority enrollments. While external factors such as Michigan's constitutional referendum opposing affirmative action (Proposition 2), the decline of state support, and the shift of state financial aid programs from need-based to merit-based have played roles, there is a growing concern that the decline of campus diversity has also been the result of an erosion of institutional commitment to diversity. The University should strive to renew its commitment and develop and implement new strategies to restore a sense of progress

Building a Sense of Pride in, Respect for, Excitement about, and Loyalty to the University: The increasing specialization of the academic and professional disciplines, the University's long tradition of decentralization, and the increasing mobility of faculty, students, and staff can sometimes erode personal commitment to general institutional goals and the values of a learning community. All too frequently, faculty, students, and staff focus primarily on personal or professional goals rather than on the welfare of the University. It is important to seek opportunities to engage the University community in both discussions of and active participation in determining the future of the institution. Beyond this, we need to develop a sophisticated and strategic internal communications effort to give members of the University a better understanding of the challenges, opportunities, and responsibilities facing the University rather than simply marketing the party line.

Re-igniting the Michigan "broad and liberal" spirit: Every effort should be made to rekindle the activist spirit that has long animated Michigan students, faculty, and staff, leading them to both identify with key issues facing our society and challenging the establishment to address these. While sometimes disruptive for the institution (and the community), this should be regarded as an appropriate and important element of the University's role as both servant and critic of society. Such activism should not only be tolerated but encouraged both as an element of the learning environment and an important responsibility of the University. Today's issues such as global sustainability, social justice, wealth inequity, and generational responsibility provide compelling opportunities for such activist engagement.

Reaffirming the Michigan Saga as a Pathfinder and Trailblazer: As we have stressed, the perception of Michigan as a trailblazer appears again and again throughout its history, as the university explored possible paths into new territory and blazed a trail for others to follow. At times, it has also been a pioneer, building the roads that others can follow. Whether in academic innovation, technology development, social responsiveness, or its willingness to challenge the status quo, Michigan's history reveals this trailblazing character. During an era of profound and rapid change, it is more important than ever that the University recapture this saga as a pathfinder.

The *Renaissance* Roadmap

As we have noted throughout this report, the world is changing rapidly, driven by the role played by educated people, new knowledge, innovation, and entrepreneurial zeal. These characteristics are driving profound changes in our world and its social institutions. They also contain the elements of what could be a renaissance in the 21st century. Since universities will play such a critical role as the source of these assets of the age of knowledge, our vision for the early 21st century involves stressing the following characteristics among our people and our programs:

Creativity
Innovation
Ingenuity and Invention
Entrepreneurial Zeal
Risk-taking
Tolerance of Failure as a Learning Experience

People

The first and most important goal of the roadmap for the Renaissance time frame is to attract and sustain exceptional students, faculty, and staff:

Recruit Outstanding Students: The University should place greater emphasis on identifying and attracting students of truly exceptional ability and creativity. This effort may require special scholarship or fellowship programs (such as the Morehead Scholars at the University of North Carolina) to augment existing need-based programs. It might also involve extending the dual admission practice (which our Medical School used to provide through its Inteflex programs) to other professional and graduate programs to attract outstanding undergraduate students. We need to reduce the disciplinary barriers between various graduate and professional programs to attract the very best graduate students.

Recruit Paradigm-Breaking Faculty: We should allocate more resources toward the recruitment and development of truly exceptional faculty through a University-wide effort. Although endowed chairs are important, this recruiting of paradigm-breaking faculty might be better served through the introduction of institution-wide appointments as University Professorships reporting directly to the Provost similar to those at leading institutions such as the University of California (University Professors) and MIT (Institute Professors) since much of the creative teaching and research will occur across disciplinary lines (convergence).

Strengthen the Emphasis on Human Resource Development: The University should continue efforts to give high priority to human resource development throughout all areas of the institution. It is important that we sustain the University's commitment to education, training, and career planning for both staff and faculty.

Intellectual

Enabling Intellectual Change: The University needs to take steps to assist its students and faculty in responding to the extraordinary pace of intellectual change. As our society increasingly values creativity and innovation, the university will be called upon to augment its traditional emphasis on "learning to know" with "learning to do", "learning to create", and

The North Campus is the *Renaissance Campus* containing the University's disciplines based on creativity.

"learning to become". Of course these latter skills have always been valued by studio- or laboratory-based disciplines such as engineering, architecture, and the arts ("doing" and "creating") and the professional disciplines ("becoming"). In fact, much of the campus infrastructure has evolved to support "doing" and "creating" (e.g., the North Campus) and "becoming" (e.g., the Medical Center). The university may need to reorganize itself quite differently, stressing forms of pedagogy and extracurricular experiences to nurture and teach the art and skill of creativity and innovation to ALL of its students. This would probably imply a shift away from highly specialized disciplines and degree programs to programs placing more emphasis on integrating knowledge.

Lowering Disciplinary Boundaries: Beyond the changing needs of a knowledge-driven society, the activities of the disciplines are rapidly converging as their boundaries become more diffuse. Biomedical advances depend increasingly on the physical sciences (atomic, molecular, and even nuclear physics) and engineering (complex systems analysis). Similarly, professional practice is changing rapidly (e.g., medical practice evolving more toward the team-based system approaches of engineering, engineering requiring the perspective of the social sciences, etc.). Key will be efforts to break down the constraints posed by disciplinary organizations, e.g., academic units such as departments, schools, and colleges, and academic degree programs at the undergraduate, graduate, and professional level. To allow faculty and students to teach, study, and learn where the need and interest are highest, we need greater flexibility. In this regard, Michigan should encourage more flexibility that spans disciplinary boundaries (e.g., centers and institutes), and university faculty appointments that could span multiple disciplines. More effort also needs to be made to coordinate faculty appointments, academic programs, research activities, and resource allocation among academic units.

"T" Graduates: An increasingly complex and rapidly changing world requires what some call "T" graduates, capable of both depth in a particular discipline as well as intellectual breadth to provide perspective. This counters the current educational philosophies adopted by many academic programs, particularly in more applied areas such as engineering, business administration, and allied heath professions, where a growing disciplinary knowledge base has largely pushed aside the "liberal education" component of an undergraduate education that is particularly important for creativity and innovation. These programs must heed the wisdom that "the purpose of an undergraduate education is not to prepare a student for their first job but rather prepare them for the last job" and restore the philosophy of a liberal education to their curriculum to produce "T" graduates.

Restructuring the Ph.D.: While the Ph.D. degree continues to be superb preparation for a research or academic career, it has become clear that most Ph.D. students will continue on to nonacademic careers in the public or private sectors. Recent national reports have challenged the excessive specialization, attrition rate, and time-to-degree characterizing today's Ph.D. programs. (Holliday, 2012) The university should provide leadership in examining and perhaps restructuring its Ph.D. programs to better serve the students enrolling in them and the society they will serve. A similar assessment and restructuring of the postdoctoral experience is also urgently needed, and the University should provide leadership for such an effort.

Transformative Research: The University should give more priority in both student and faculty recruiting and resource allocation to areas with the potential for truly transformative research, i.e., breaking the current knowledge paradigms. This will require both the development of flexible funding to stimulate high-risk research, as well as organizational structures similar to the "advanced research project agencies" (e.g., DARPA, ARPA-E, ED-ARPA) now appearing in several federal research agencies.

Translational Research: In a similar sense, the University should also build organizations and programs capable of translational research, i.e., linking fundamental scientific discovery with the use-inspired technological innovation to serve society. The recently acquired Pfizer Global Research Center (the North Campus Research Center) provides an ideal site for the translational research sought by federal sponsors through new programs such as regional innovation hubs.

Strategic Alliances: Over a longer time frame, the higher education enterprise in America will clearly undergo significant restructuring. Anticipating this, the University of Michigan should give high priority to forming and sustaining strategic alliances with regional institutions (e.g., the CIC universities), national institutions (e.g., the AAU), and international institutions (e.g., Europe and Asia). We also should establish alliances with other knowledge-based institutions in the public and private sector (e.g., software and entertainment companies or national laboratories and institutes.)

Culture

Stimulate a Sense of Adventure, Excitement, and Risk-taking: During a period of rapid change, the University's capacity to try new things, to be adventurous and experimental, has become increasingly important. The unusual size, comprehensiveness, and quality of the institution provide us with an unusual capacity for such risk-taking. But, ironically, Michigan's culture at times can become quite conservative and adverse to risk, particularly during times of financial stress or pre-occupation with growth (enrollments, campus, bureaucracy). Hence, an early objective should be to create a more fault-tolerant community, in which risk-taking is encouraged, failure is anticipated and tolerated, and creativity and innovation are prized.

Next-Generation Leadership: Throughout the University, the selection and appointment of leaders who have bold visions, energy, and a sense of adventure is key to preparing for the future. Simply selecting leaders to maintain the status quo is dangerous for an institution such as Michigan, particularly during an era of rapid change. The University needs to build a leadership team that is committed to the necessary transformations in the University and that relishes the role of leading during a time of challenge and change.

Possible Path-Finding Initiatives

A University College: The University should consider developing a more coherent academic program for all undergraduates, reducing the amount of specialization offered in degree programs, and striving to provide instead a more general liberal learning experience. It should expand experiments in pedagogical alternatives to classroom learning, including collective learning experiences based on studio or laboratory paradigms, greater use of social networking (e.g., wikis and MOOCs), immersive environments such as those characterizing the gaming world (e.g., World of Warcraft, Minecraft), as well as more advanced learning technologies such as AI-based cognitive tutors and learning analytics.

Universitas --> To Know

Renaissance --> To Do, To Create

Enlightenment --> To Become

Learning Objectives of the Vision Themes

The presence of an unusually broad array of professional schools is one of the great strengths of the University and clearly one of the major factors in attracting outstanding undergraduates. We need to develop closer linkages between undergraduate education and the faculty of these schools, so that students could have the opportunity to explore and choose among various careers. Indeed, many professional-school faculty members seek more direct interaction with undergraduate students.

Yet here one of the great strengths of the University in pursuing a vision of creativity is its deep commitment to the liberal arts. Ironically, perhaps Steve Jobs of Apple stated this best: "It is in Apple's DNA that technology alone is not enough. It is technology married with the liberal arts, with the humanities, that yields us a result that makes our heart sing in our devices. The reason why Apple is able to create produces like the iPad is because we always try to be at the intersection of technology and the liberal arts, to get the best of both!"

Perhaps such a vision is needed at Michigan!

The Renaissance Campus: Largely due to historical accident, the University has located on its North Campus an unusual concentration of academic programs characterized by the common intellectual activities of creativity and innovation (e.g., art, architecture, music, theatrical arts, engineering, information technology, and design), along with very unusual commons facilities to bring together students and faculty from these disparate disciplines. This colocation of the University's creative disciplines provides the University with the opportunity to address the rapid convergence of their intellectual activities, e.g. linking the creativity of the arts with the technological innovation of engineering and architecture. It also positions the University to respond to the increasing importance attached to innovation in our society. Indeed, one might even think of the North Campus, its academic programs, faculties, and students, as the "Renaissance Campus" of the University (a designation once suggested by the North Campus deans).

Beyond the location of the various schools and colleges of the University most deeply engaged in the intellectual activity of creativity, the North Campus also has unique common spaces such as the Duderstadt Center, a "media union for creativity", and highly interdisciplinary academic programs stressing creative activities such as design and performance.

The "New" University: Experience has revealed the difficulty of approaching university transformation by changing existing programs and activities. While such a direct approach may suffice for incremental changes at the margin, an effort to achieve more dramatic change usually creates so much resistance that little progress is possible. It is sometimes easier to take a "green-field" approach by building separately a model of the new paradigm, developing the necessary experience with it, and, then, propagating successful elements of the model to modify or, perhaps, replace existing programs.

One possible approach to major university transformation taken in earlier and more affluent times was to build a separate campus. The efforts of the University of California in the 1960s to explore academic colleges built around research themes at UC-San Diego and residential learning at UC-Santa Cruz are examples of this approach. However, today's resource-limited environment make it difficult to justify such separate new campuses to explore new educational paradigms–not to mention finding sites comparable to the bluffs overlooking the Pacific. But there is a more important reason to consider an alternative approach: we believe that it is far more effective to develop and explore such new paradigms of the university directly, within an existing university community, since this more quickly propagates successful efforts to the host institution.

To this end, the University might consider creating a "New University" within its existing organization to provide an environment in which creative students and faculty could join with colleagues from beyond the campus to develop and test new paradigms of the university. In some ways, the New University would be a laboratory where the fundamental missions of the university—teaching, research, service, extension—could be redeveloped and tested. But it would also be aimed at developing a new culture, a new spirit of excitement and adventure that would propagate to the university at large. In such an academic enterprise, the University would hope to build a risk-tolerant culture in which students and faculty were strongly encouraged to "go for it," in which failure is accepted as part of the learning process, and is associated with ambitious goals rather than poor performance.

The New University could have both a physical and a virtual presence. In terms of structure, the New University might be organized with convergent themes among the disciplines. Furthermore, while it could offer academic degrees, such programs would stress stronger linkages among undergraduate, graduate, professional, and lifetime education programs than those offered by the traditional university. The New University could strive to more effectively integrate the various activities of the University by engaging its students in an array of teaching, research, service, and extension activities. The New University would almost certainly involve an array of outreach activities, e.g., linking alumni to the on-campus activities of the University or providing richer and more meaningful international experiences for students.

While the New University would enroll a significant number of students, it would not have a large cohort of permanent faculty or staff. Rather, it would draw faculty members from across the University and around the world who would become associated with the New University for specific programs. This would allow it far greater flexibility, since it could avoid the constraints posed by faculty appointments and tenure.

The success of the New University would depend in large part upon its governance and advisory structure. Although it would report through the normal University channels, it could also have its own steering board comprised of leaders from many sectors of society. It would also make extensive use of external advisory groups for its various activities.

The Roadmap to *Enlightenment*

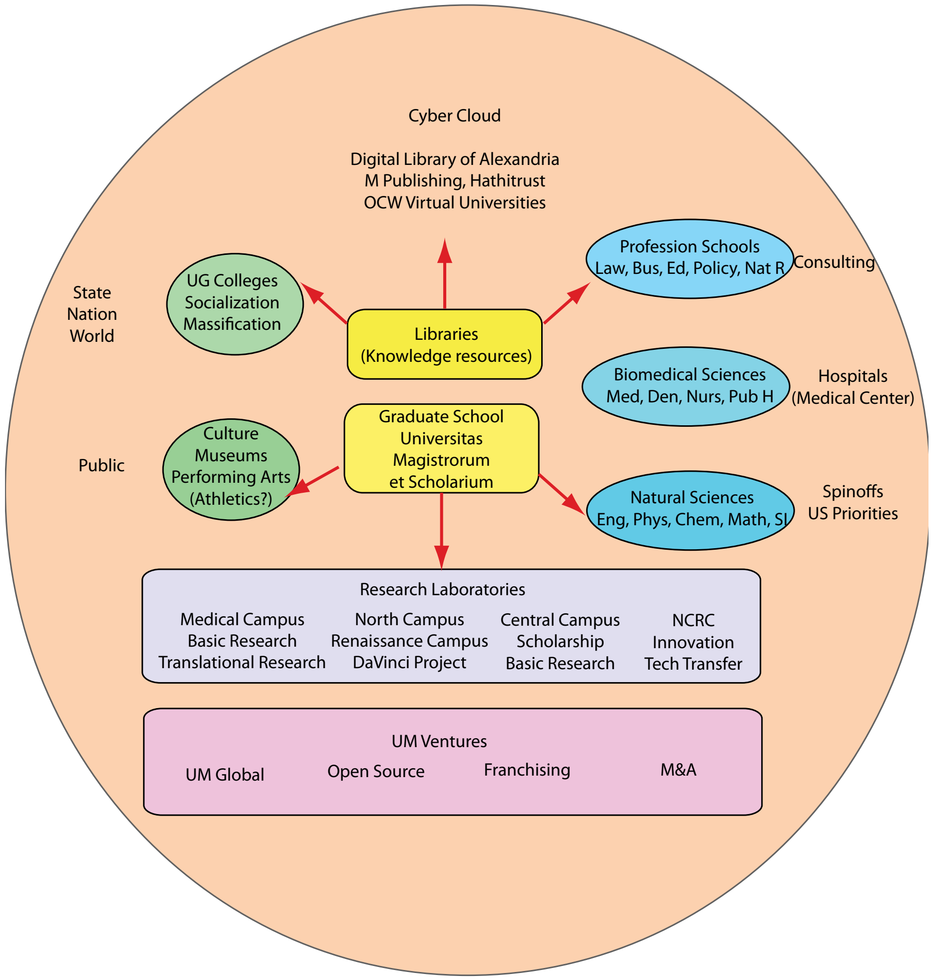
The final vision proposed for the University is the theme of Enlightenment, spreading the light of learning and knowledge to the world, as its public purpose for its third century. Here we suggest major elements of a possible roadmap to this future based upon several of the paradigms discussed in Chapter 5:

- The emergence of a *universitas magistrorum et scholarium* in cyberspace.
- The power of network architectures in distributing knowledge and learning
- The perspective of learning organizations as ecologies that evolve and mutate into new forms
- The university as the prototype of an emergent global civilization

Of course the themes we have suggested for comprising at least a rough roadmap to the Enlightenment vision of the University of Michigan's third century are highly speculative if not utopian in nature. They need to be better defined, refined, and translated into practical steps that the University can begin to take. But such is the case with any bold vision. And, interestingly enough, the University is already taking important steps down the path sketched out by this roadmap.

Capturing and distributing knowledge to the world: We have noted the leadership role that the University has in the massive digitization of printed materials and the use of these digital repositories (e.g., JSTOR, Google Book, HathiTrust). In fact, since the University's leadership of the HathiTrust has led to it creating the largest digital library in the world, one might suggest that Michigan is already serving as the nucleus of what may become a 21st century analog to the great Library of Alexandria.

The University is also playing an important leadership role in the open resource movement, using its influence to push for open access to research data and other scholarly materials. Finally, its School of Information, one of the first such academic programs merging traditional library science with informatics and other digital age technologies, provides leadership in both education and research in areas that will be critical to unprecedented access to the world's knowledge.

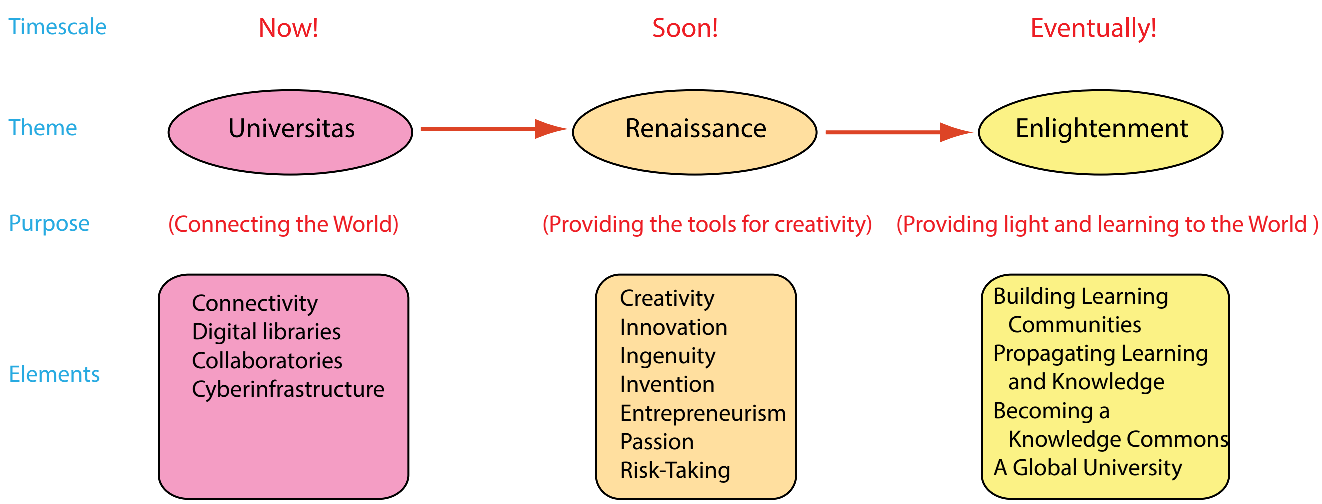


The academic "core" in a cyberspace "cloud".

Open Education Resources: Although the University has some participation in efforts such as the OpenCourseWare movement and digital course development and distribution through iTunes, Amazon, and other mechanisms, its recent involvement is limited to only a few academic units (most notably the School of Medicine). However, the University's involvement in new efforts such as massively open online courses (MOOCs) through organizations such as Unizen and Coursera will hopefully catalyze a greater leadership role in these important areas.

Cyberinfrastructure: In recent years, the University has once again begun to develop strategies and make investments to restore the position of leadership it once had in developing and deploying advanced cyberinfrastructure in partnerships with leading IT companies. The recent decision to select Google as the lead system integrator for collaboration technology is an important step in this direction. But here the University must embrace a balanced strategy, both utilizing advanced technology in an efficient and cost-effective manner, and partnering with leading companies in both technology development and application for academic environments (much as it has in the past through efforts such as MTS, CAEN, NSFnet, Internet2, and Sakai).

Networking: Clearly advanced network development is key to the Enlightenment vision. The University has long had leadership in the development of national and international networks (e.g., NSFnet, the Internet, Internet2). Yet, simply providing high-speed network links between campuses and other



knowledge institutions is only the first step, since such connectivity must be distributed to the desktop, laptop, and laboratory on the campus and to the homes of faculty and students in the surrounding community. Here the University is also participating in the Gig U effort to assemble a coalition of the nation's leading research universities to challenge industry (e.g., carriers such as AT&T, Verizon, and Comcast and technology companies such as Google and IBM) to provide ultra-high bandwidth connectivity through the campuses and surrounding communities (much like the Goggle community fiber program).

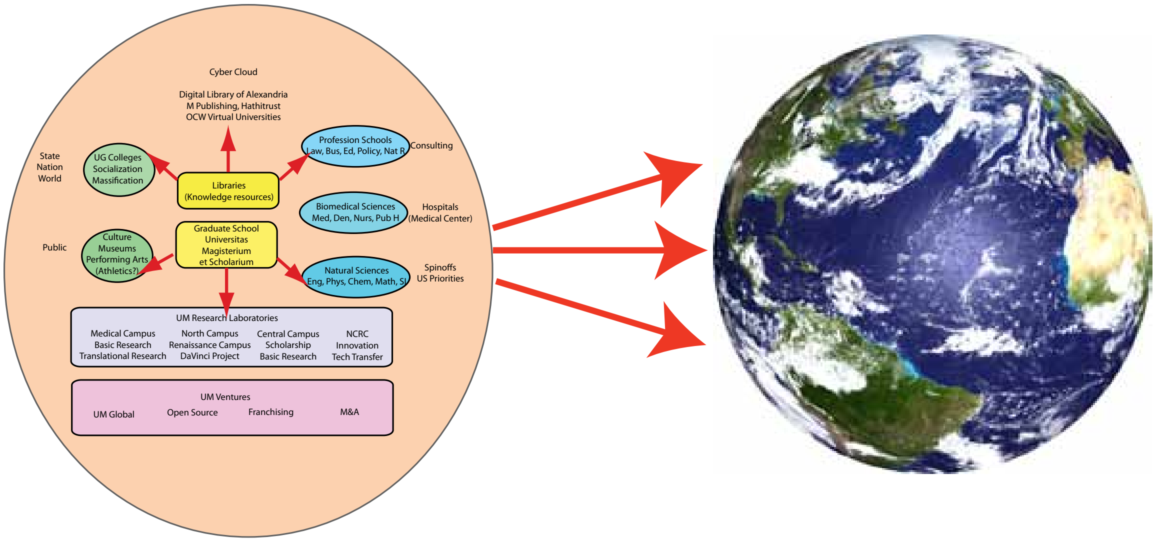
Advanced Learning Environments: The University should launch a major effort to develop and deploy advanced learning environments–particularly those enabling social networking and immersive environments (including "sim-stim"–high fidelity simulation of all the senses at a distance). Its past experience with the development of open source curriculum management software such as CTools and Sakai positions it well for this effort.

Establishing a Global Footprint: Clearly the University of Michigan will need to establish a global footprint to achieve this vision. While it certainly has a strong international reputation in higher education, its current strategy of developing selected partnerships at the institution level will need to be expanded considerably. To some degree this is a "branding" exercise, but more significantly, it will require developing strategic relationships with key international higher education and technology organizations such as OECD, the European University Association, and the LERU universities and their counterparts in Asia.

Building the Necessary Scholarly Foundation for the Effort: To enable such a bold effort, the University will have to establish a strong intellectual foundation of faculty scholarship in areas key to a global knowledge and learning enterprise. Here the University's great strength in the social sciences, along with its many research institutions and professional schools position it well for such an effort.

Taking Advantage of the University's Structure: As we have noted, the University of Michigan is characterized by a highly decentralized organizational structure, in effect, as a loosely coupled adaptive ecosystem. Interestingly enough, this is also similar to the structure of the Internet itself, which has little central control and instead depends upon activity on the edge as it adapts to changes and demands. Hence the unusual structure of the University provides it with an extraordinary capacity to propagate knowledge and learning similar to the Internet itself.

The Public Character of the University of Michigan: The key themes of the 18th Century Enlightenment, the rational distribution of freedom, the universal access to knowledge, and the use of collective experiences stressed that knowledge, learning, and connectivity,



A Public Purpose for the Third Century:
Providing the light of knowlidge and learning
to the World!

were public goods. The public communities of those eras, the salons, seminars, and academies, today have evolved into new forms such as social networks and data clouds. Yet they remain very much public "unions" characterized by "universality", much as the University of Michigan is very much a public institution (although clearly not longer restricted to a state but rather serving the world itself).

So, How Does One Lead Michigan to 2030?

As many leaders in higher education have come to realize, our changing environment requires a far more strategic approach to the evolution of our institutions at all levels. It is critical for higher education to give thoughtful attention to the design of institutional processes for planning, management, and governance. Key is the recognition that in a rapidly changing environment, it is important to develop a planning process that is not only capable of adapting to changing conditions, but to some degree capable of modifying the environment in which the university will find itself in the decades ahead. We must seek a progressive, flexible, and adaptive process, capable of responding to a dynamic environment and an uncertain—indeed, unknowable—future.

There are always opportunities to control constraints—and the future—if one takes a proactive approach. Universities are rarely playing in a zero-sum game. Instead, they may have the opportunity to increase (or decrease) resources with appropriate (or inappropriate) strategies. The university is never a closed system. Put in more engineering terms, any complex system can be designed in such a way as to be less sensitive to initial and/or boundary conditions. A successful strategic planning process is highly iterative in nature. While the vision remains fixed, the goals, objectives, actions, and tactics evolve with progress and experience. During a period of rapid, unpredictable change, the specific plan chosen at a given instant is of far less importance than the planning process itself. Put another way, one seeks an "adaptive" planning process appropriate for a rapidly changing environment and a loosely coupled adaptive system such as a university.

In an institution characterized by the size and complexity of the contemporary research university, it is usually not appropriate (or possible) to manage centrally many processes or activities. One can, however, establish institutional priorities and goals and institute a process that encourages local management toward these objectives.

Institutions all too frequently chose a timid course of incremental, reactive change because they view a more strategically-driven transformation process as too risky. They are worried about making a mistake, about heading in the wrong direction or failing. While they are aware that this incremental approach can occasionally miss an opportunity, many mature organizations such as universities would prefer the risk of missed opportunity to the danger of heading into the unknown.

But, today, incremental change based on traditional, well-understood paradigms may be the most dangerous course of all, because those paradigms may simply not be adequate to adapt to a future of change. If the status quo is no longer an option, if the existing paradigms are no longer viable, then transformation becomes the wisest course.

Our challenge is to tap the great source of creativity and energy of outstanding faculty, students, and staff, working at the grassroots level of the academic enterprise of the University in a way that preserves our fundamental mission and values. We need to continue to encourage our tradition of natural evolution, which has been so successful in responding to a changing world, but do so with greater strategic intent. We must also develop a greater capacity to redirect our resources toward our highest priorities. Rather than allowing the university to continue to evolve as an unconstrained, transactional, entrepreneurial culture, we need to guide this process in such a way as to preserve core missions, characteristics, and values.

Perhaps because of its early founding as an "Enlightenment" institution or the almost total autonomy it was given when founded by the state's first constitution (quite unique among American universities), the University of Michigan is structured as a biological ecosystem, evolving as a loosely coupled adaptive system in response to external challenges and opportunities much like a tropical rain forest. While leadership is important to identify areas of opportunity and to direct resources to those parts of the University capable of responding, the initiatives, energy, and excellence of the institution always comes from the grass roots, from the abilities and commitment of its students, faculty, and staff and the integrity of its academic programs.

The University of Michigan, Circa 2030...and Beyond

So what is next? Who knows? As we look even further into an unknowable future, the possibilities and uncertainties become even more challenging. Attempting to predict the future is always a hazardous activity. We generally overestimate change in the near term and underestimate it for the longer term, in part because we usually tend to extrapolate what we know today into a future that becomes increasingly beyond our imagination. It is very difficult to peer over the horizon and imagine a future characterized by the possibility that anyone with even a modest Internet or cellular phone connection will have access to all of the recorded knowledge of our civilization along with ubiquitous learning opportunities and access to network-based communities through the world.

In particular, what might we anticipate over the longer term as possible future forms of an institution such as the University of Michigan? The monastic character of the ivory tower is certainly lost forever. Although there are many important features of the campus environment that suggest that most universities will continue to exist as a place, at least for the near term, as digital technology makes it increasingly possible to emulate human interaction in all the senses with arbitrarily high fidelity, perhaps we should not bind teaching and scholarship too tightly to buildings and grounds. Certainly, both learning and scholarship will continue to depend heavily upon the existence of communities, since they are, after all, high social enterprises. Yet as these communities are increasingly global in extent, detached from the constraints of space and time, we should not assume that the scholarly communities of our times would necessarily dictate the future of our universities. For the longer term, who can predict the impact of exponentiating technologies on social institutions such as universities, corporations, or governments, as they continue to multiply in power a thousand-, a million-, and a billion-fold?

But there is a possibility even beyond these. Imagine what might be possible if all of these elements are merged, i.e., Internet-based access to all recorded (and then digitized) human knowledge augmented by powerful search engines and AI-based software agents; open source software, open learning resources, and open learning institutions (open universities); new collaboratively developed tools (Wikipedia II, Web 2.0); and ubiquitous information and communications technology. In the near future it could be possible that anyone with even a modest Internet or cellular phone connection will have access to the recorded knowledge of our civilization along with ubiquitous learning opportunities and access to network-based communities throughout the world (perhaps even through immersive environments through virtual or augmented reality).

Imagine still further the linking together of billions of people with limitless access to knowledge and learning tools enabled by a rapidly evolving scaffolding of cyberinfrastructure, which increases in power one-hundred to one thousand-fold every decade. This hive-like culture will not only challenge existing social institutions–corporations, universities, nation states, that have depended upon the constraints of space, time, laws, and monopoly. But it will enable the spontaneous emergence of new social structures as yet unimagined–just think of the early denizens of the Internet such as Google, Facebook, Amazon... In fact, we may be on the threshold of the emergence of a new form of civilization, as billions of world citizens interact together, unconstrained by today's monopolies on knowledge or learning opportunities.

Perhaps this, then, is the most exciting vision for the future of knowledge and learning organizations such as the university, no longer constrained by space, time, monopoly, or archaic laws, but rather responsive to the needs of a global, knowledge society and unleashed by technology to empower and serve all of humankind. And all of this is likely to happen during the lives of today's students. These possibilities must inform and shape the manner in which we view, support, and lead higher education. Now is not the time to back into the future.

To quote from the 2010 Glion Declaration:

"For a thousand years the university has benefited our civilization as a learning community where both the young and the experienced could acquire not only knowledge and skills but also the values and discipline of the educated mind. It has defended and propagated our cultural and intellectual heritage, while challenging our norms and beliefs. The university of the twenty-first century may be as different from today's institutions as the research university is from the colonial college. But its form and its continued evolution will be a consequence of transformations necessary to provide its ancient values and contributions to a changing world" (Rhodes, 2010).

The emergence of a new civilization
based on global learning institutions

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Appendix A: A Preamble

From Disney's Spaceship Earth in EPCOT

(Narrated by Judi Dench)

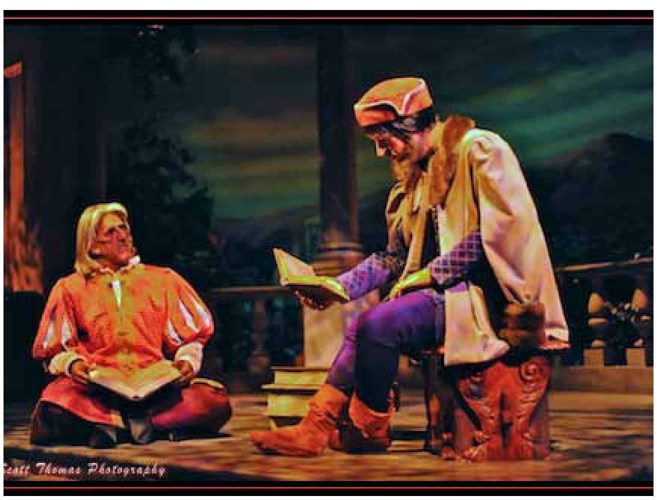
Like a grand and miraculous spaceship, our planet has sailed through the universe of time; and for a brief moment we have been among it's passengers. But where are we going? And what kind of future will we discover there? Surprisingly, the answers lie in our past. Since the dawn of recorded history, we've been inventing the future one step at a time. So let's travel back in time together. I'll show you how our ancestors created the world we know today, and then it will be your turn to create the world of tomorrow.

Here, in this hostile world, is where our story begins. We are alone, struggling to survive. It takes 15,000 years to come up with the next bright idea: recording our knowledge on cave walls.

Now, let's move ahead to ancient Egypt, because something is about to happen here that will change the future forever. This unknown Egyptian pounding reeds flat is inventing papyrus—a sort of paper. Papyrus, in turn, creates better record keeping of plans, designs, and unfortunately taxes. But it also brings with it the dawn of great civilizations.

The Phoenicians create a simple, common alphabet, adaptable to most languages. The ancient Greeks were great inventors of the future. First, they established public schools, and then begin teaching an intriguing new subject called mathematics. And with math comes mechanical technology and the birth of a high-tech life we enjoy today.

It turns out there are copies of some of these books in the libraries of the Middle East, being watched over by Arab and Jewish scholars. The books are saved, and with them our dreams of the future. In the meantime, here in Europe, monks toil endlessly, recording books by hand—but that is about to change.



With lessons learned from the Greeks, the Romans create a powerful empire. To move their armies around, they build a system of roads all over the known world. Rome built the first "world wide web," and it's leading us into the future.
But then we hit a roadblock—Rome falls, and the great Library of Alexandria in Egypt is burned. Much of our learning is destroyed—lost forever… or so we think.

In 1450, Gutenberg invents the movable type printing press. Now knowledge can travel as fast as these new books… and travel they do.
Books make it easier to invent the future in every field, and the result is an incredible explosion of innovation that we call the Renaissance.

Books make it easier to invent the future in every field, and the result is an incredible explosion of innovation that we call the Renaissance.
Books, it seems, were just the beginning. Now communication technology races headlong into the future, and soon people all over the world are sharing life's most important moments faster than ever before.

What if everyone could have one of these amazing machines in their own house? There's just one problem: they're as big as a house. The solution comes in, of all places, a garage in California.

By now, we're all communicating from anywhere on Earth—and in 1969, from somewhere else. To send a man to the moon, we had to invent a new language, spoken not by man, but by computers—at first very large, very expensive computers—but we see the potential.

. Together, we form a super network that goes with billions of interactions, and once again we stand on the brink of a new Renaissance.
After 30,000 years of time travel, here we are—a truly global community, poised to shape the future of this, our Spaceship Earth.

Appendix B

A Summary of UM Computer History

The University of Michigan has long provided national leadership for higher education in the application of technology to teaching and research. Perhaps no area illustrates this more vividly that its leadership in the development and application of computers and, more broadly, information and communications technologies. Michigan frequently not only easily adapted to each transformation in these technologies, but led in the transitions of early mainframe computers to timesharing to networked computer workstations to the Internet and today's global networks of data centers, search engines, big data, and open knowledge resources

1950s and 1960s

During the post WWII, Michigan was among the earliest universities to explore the use of the digital computers. Michigan faculty member Arthur Burkes participated in the development of the first electronic computer, ENIAC, and obtained a portion of this machine for display in the University's Computer Science and Engineering Building. The University's Willow Run Laboratories installed an early computer, MIDAC (Michigan Digital Automatic Computer) in 1952, but the use of computers in teaching and research really began with a series of IBM mainframe computers, the IBM 650, 704, and 7040, installed on campus during the 1950s and 1960s. University faculty members including Bernard Galler, Donald Katz, James Wilkes, and Brice Carnahan led the efforts to apply these computers to both teaching and research, developing the first courses in computer programing and later new academic degree programs such as Computer and Communications Sciences (in LS&A) and Computer Science and Engineering (in Engineering).

But more significantly, the University led in the development of the software for these computers, first developing the MAD (Michigan Algorithm Decoder) programming language in 1960 and then one of the first time-sharing operating systems, MTS (Michigan Terminal System), for building a University-wide network using the IBM 360/67 mainframe computer in 1966. The MTS system, operated by the University Computer Center directed by Robert Bartels, not only became the workhorse of the University's teaching and research activities, but soon was adopted by many other universities.

The University's leadership in networking technology soon led to a statewide computer network, MERIT, (Michigan Education Research Information Triad), linking together the major universities in Michigan (initially UM, MSU, and WSU), which was to play a major role in creating the Internet in the 1980s.

1970s and 1980s

The University's time-sharing system continued to evolve through the 1970s and 1980s, moving from IBM mainframes to more powerful Amdahl computers, and gaining a reputation as one of the nation's leading computer environments for teaching and research. But the very success of the MTS system, its centralized structure, and its home-grown character, rapidly lost ground to the new generation of minicomputers such as DEC's VAX systems for science and engineering applications. By the end of the 1970s, most engineering and science departments at top research universities had acquired their own VAX systems. Yet, Michigan remained not only moored to the increasingly aging mainframe-based MTS system, but also to centrally administrated computer policies that prevented

From sliderules and calculators to Eniac to early IBM mainframes and finally to the Michigan Terminal System

academic programs from breaking away and acquiring more advanced computing environments. In fact, every purchase of a computer had to be approved by a central committee at the University.

This was a topic of personal interest, since my own career had largely paralleled that of the digital computer. My particular area of research, nuclear energy systems (nuclear reactors, nuclear rockets, thermonuclear fusion), was not only heavily dependent upon state-of-the-art computing, but it had actually driven much of computer development. During the 1960s and 1970s I had done much of my work using Atomic Energy Commission supercomputers at AEC laboratories such as Los Alamos and Livermore. Although my research made use of the very fastest computers in the world, several of our faculty members (including Dick Phillips and Bill Powers of Aerospace Engineering) got me interested in the use of the first microcomputers such as the TRS-80 and Apple II for instructional purposes. In fact, I taught one of the very first introductory computer courses on these systems in the late 1970s. From these experiences, I was convinced that the College simply had to break away from the University's MTS system and build its own computing environment, more suited to its needs. I was convinced that the digital computer would rapidly evolve from simply a tool for scientific computation and information processing into an information technology infrastructure absolutely essential to all of our activities, from research to instruction to administration. Hence, to build a leading engineering college, we would have to become a leader in information technology. This view was shared by many members of the College.

Dan Atkins assumed the leadership for this effort, assisted by Dick Phillips, Lynn Conway and other members of the faculty. We set a rather ambitious goal:

To build the most sophisticated information technology environment of any engineering college in the nation, an environment that would continually push the limits of what could be delivered in terms of power, ease of use, and reliability to our students, faculty, and staff. The system was called CAEN, the Computer Aided Engineering Network, a name that reflected its functional architecture as a sophisticated information technology network integrating the College's instruction, research, and administrative activities together with both oncampus users (students, faculty, staff) and off-campus participants (industry, government, alumni). More technically, CAEN was envisioned as a distributed intelligence, hierarchical computing system linking personal computer workstations, superminicomputers, mainframe computers, function-specific machines (CAD/CAM, simulation) and gateway machines to national networks and facilities such as supercomputer centers. The network was designed to support not only general scientific computing, but computer-aided instruction, administrative services, and access to technical and bibliographic databases.

We first had to fight a battle with the University administration to allow us to break away from the MTS system. Fortunately it was easy to convince Harold Shapiro and Bill Frye that they needed to encourage more diversity in computing, and in particular, allow some units to move far out on the curve of advanced computing as pathfinders for the rest of the University. Engineering and Business Administration were given the go-ahead to build their own environments (which would eventually lead to the disappearance of MTS, although it would take almost a decade).

We launched this transition from a mainframe time-sharing system to microcomputer/workstation networks by first providing every member of the faculty with a personal computer (a choice of either an IBM PC or an Apple II computer). Actually, there was an interesting wrinkle to this offer, since we asked each faculty member also to take a second computer home, the rationale being the likelihood that their families would serve as an additional stimulus to become "computer literate". Interestingly enough, this program had unexpected impact when the teenage sons of one faculty member became so adept at programming the Apple II computer brought home by their father, that they managed to develop commercially successful software for editing photographic images. You may have heard of the software…Adobe's Photoshop! (Developed by Tom and John Knoll, sons of faculty member Glenn Knoll.)

We next began to acquire several networked clusters of state-of-the-art computer workstations for research (Apollo, Sun, HP, Apple Lisas, Silicon Graphics). We faced a very major challenge in providing adequate computing resources for our students, since our large enrollments (6,000) would require a massive investment. To address this, we took two very important steps: We persuaded the University to allow us to charge students a special $100 per term computer user fee to help support their computing environment. This generated $1.5 million each year that we then could use to buy (or even debt-finance) computer equipment. We made absolutely certain that every penny of these fees (along with significant contributions from the College) went entirely to equip numerous student computing clusters that would be restricted solely for the use of students. To provide a vivid demonstration of just what the students were getting for their fees, we converted two large lecture rooms on the first floor of the Chrysler Center into a gigantic computer cluster, equipped with over 100 of the new Apple Lisa workstations. This was quite a sight—probably the largest collection of Apple Lisas that ever existed—and it really impressed the students. We adopted the philosophy that these were the students' computers, without any constraints on how they could use them. Similar computer clusters were later distributed across the University.

The second element of the plan for students involved developing a mechanism to help them purchase their own personal computers, since we realized that the University would never have sufficient assets to equip all enrolled students. We explored the possibility of negotiating very deep discounts (60% or more off list price) with key vendors such as Apple and IBM. They were quite willing to do this, but the principal hangup was with the University, nervous that the local computer stores might complain to the state legislature that we were undercutting their business. After considerable effort, we finally managed to convince Shapiro and Brinkerhoff that the leading universities would be achieving massive deployment of personal computers

From Apple II to IBM PCs to Apple Lisas to the Computer Aided Engineering Network (led by Dick Phillips, and Dan Atkins with the help of Steve Jobs) and finally the MacIntosh and beyond.

to students through such bulk discounts, and that Michigan would rapidly fall behind if we did not do the same. Since I suspected that the impact on local retailers would be very positive from the secondary hardware and software sales stimulated by the student program, we negotiated a separate agreement with them to sell their wares when the students picked up their computers through the University. Since the first major deliveries occurred early in the fall, we began to call these events the Fall Computer Kickoff Sale. It was quite a hit with the students, particularly when new systems such as the Macintosh appeared. The number of University students acquiring their own computers began to rise rapidly, stimulating both the College and the University to install appropriate networking capability in the residence halls and University buildings.

The final step in bringing CAEN to the level of sophistication we had envisioned was made possible by a $2 million gift from General Motors that allowed us to acquire over 350 high-end computer workstations, connected with high speed networks, to serve the advanced needs of students and faculty. Our philosophy was simple: We were determined to stay always at the cutting edge, but with a very strong service focus. We sought to remove all constraints on computing, with no limit whatsoever on student and faculty use. We went with a multivendor environment, moving with whatever technology was most powerful.

Needless to say, these were highly controversial issues in the early 1980s, particularly at the University of Michigan. But as a result, by the mid-1980s the University could boast one of the most sophisticated computing environments in the world, a fact of major importance to recruiting outstanding faculty and students.

But more important, the leadership and experience of the University, both in the development of distributed workstation networks and in the statewide MERIT network led by Eric Aupperle, coupled with the recruiting of Douglas van Houweling as chief information officer, led to an effort to join with IBM and MCI (a 1980s telecom company) to compete successfully for grant to build a national network (NSFnet) that would link the nation's scientists with the supercomputer centers of the National Science Foundation. The MERIT-IBM-MCI team was able to address the explosive use of this new network, growing at rates of 10% a month, both because of the Michigan experience and the decision to use the TCP-IP protocols developed by the Department of Defense Arpanet. Because of this success, the federal government supported the extension of the NSFnet scientific network to include other national networks, creating an "Internetwork", which would be managed by Michigan and its partners until the early 1990s. Of course, this was the Internet, which the Michigan team led through a new organization, Advanced Network Technologies, until it was finally spun off to the commercial sector in 1993.

1990s

The opening of the Media Union in 1996 was yet another significant and tangible commitment by the University of Michigan, in partnership with the State of Michigan, to provide all members of the University community access to some of the most sophisticated and transformational tools of the emerging digital revolution. Conceived as a model for "the university of the future", the North Campus deans viewed the Media Union project as an effort to create a physical environment to meet the rapidly changing character of teaching and research for many years to come, in a sense of "…designing a building full of unknowns."

The University retained the architectural firm descended from the famous architect, Albert Kahn, who had designed much of the University campus in the early 20th century, as well as many of the leading buildings in Detroit. The design team of deans, faculty, and staff responsible for the program of the new facility envisioned it as more akin to the MIT Media Lab for students and faculty of the North Campus academic programs. It was designed as a high-tech collection of studios, laboratories, workshops, performance venues and gathering and study space for students. Its original program statement in 1993 portrayed it as an Internet portal to the world (since the Internet was still rather new at that time). Although it was designed to provide space for the library collections of the College of Engineering and Schools of Art and Architecture, its function as a "traditional" book-based library was never a major part of the vision. Instead it was a place intended for collaboration and innovation in teaching and learning, a place where students, faculty, and staff could access a technology-rich environment, a place open to all "who dared to invent the future".

More specifically, the resulting 250,000 square foot facility, looking like a modern version of the Temple of Karnak, contained over 500 advanced computer workstations for student use. It had thousands of network jacks and wireless hubs for students to connect their laptops to work throughout the building or in its surrounding plazas and gardens during the summer. The facility contained a 500,000 volume library for art, architecture, science, and engineering, but perhaps more significantly, it was the site of several of our major digital library projects (including the JSTOR project, the first of the national digital libraries). There was a sophisticated teleconferencing facility, design studios, visualization laboratories, and a major virtual reality complex. Since art, architecture, music, and theater students worked side-by-side with engineering students, the Media Union contained sophisticated recording studios and electronic music studios. It also had a state-of-the-art sound stage for digitizing performances, as well as numerous galleries for displaying the results of student creative efforts. To serve the unique needs of students and faculty in these areas, the Media Union was designed to open 24 hours a day, seven days a week, so that students have round-the-clock access to its facilities.

Over the past two decades since it opened, this facility "full of unknowns" has become the home for a large and evolving collection of new information and communications technologies far beyond the resources that any one school or college could acquire and maintain. The Media Union's collection of digital assets and resources requires constant renewal with the latest versions of software and hardware, and an expert team of professionals who enable U-M users to get up-to-speed and use them productively for innovative research and teaching. The Media Union rapidly became one of the most active learning spaces in the University, providing thousands of students with 7x24 hour access to rich resources including libraries, advanced technology, workshops, performance venues, and high quality study and community gathering spaces. The center has evolved into an innovative center for discovery, learning, invention, innovation, demonstration, and deployment utilizing state-of-the-art technologies and facilities and assisted by expert staff. In a sense, it serves as a new form of public good, an innovation commons, where students and faculty would come to work together with expert staff mentors to develop the skills and tacit learning acquired through studios, workshops, performance venues, and advanced facilities such as simulation and immersive environments. It encourages experimentation, tinkering, invention, and even play as critical elements of innovation and creative design.

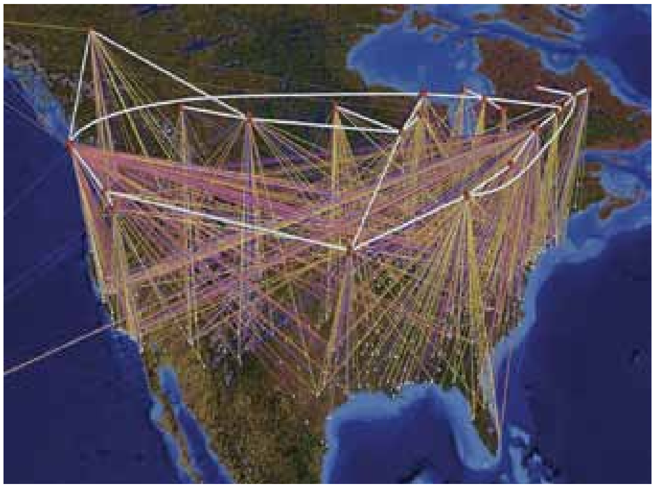
Rationalizing significant investments in cutting-edge resources by enabling free access to a shared, expertly supported collection of assets has enabled a widespread culture of innovation in digital technologies at the U-M. Students and faculty are free both to envision and to lead, hands-on, change in disciplines being transformed by the digital revolution – from engineering, the performing and design arts, and medicine, to economics and government.

In 2004, in keeping with a long-standing tradition of naming an appropriate building after each former president, the Media Union was renamed the James and Anne Duderstadt Center, or more commonly known to students simply as "the Dude". Perhaps one student best captured the role of the center when asked to explain its purpose as: "The Dude is the place you go to make your dreams come true!"

The University also continued its leadership in advanced network technology. After spinning off University management of the Internet in 1993, Doug van Houweling launched a new initiative, Internet2, which created a consortium of research universities and companies to build and operate an advanced network for research purposes. The State of Michigan recognized the importance of this effort and invested $10 million to help it get up and running. For several years this effort was managed by the University of Michigan, until after a change in UM leadership, the leadership role was passed along to Indiana University. Eventually, in the early 2000s, disagreement in providing financial assistance to the organization led to a move of most of its operations to the Washington area.

During the 1990s the University seriously considered launching a "skunkworks" operation to

The Media Union (later named the Duderstadt Center) and the Angell-Haven computer center provided state of the art cyberinfrastructure environments for students



Internet 2 and the Abilene Computer Network

The Michigan Virtual University

explore and develop various paradigms for what a 21st Century university might become. Eventually, rather than building an independent research center, we instead decided to take our smallest academic unit, the former School of Library Science, and put at its helm one of our most creative scientists, Dan Atkins, with the challenge of developing new academic programs in "knowledge management." The result has been the rapid evolution—indeed, revolution—of this unit into a new School of Information, the first such academic program in the nation.

This new school is committed to developing leaders for the information professions who will define, create, and operate facilities and services that will enable users to create, access, and use information they need. It intends to lead the way in transforming education for the information professions through an innovative curriculum, drawing upon the strengths of librarianship, information and computer science, business, organizational development, communication, and systems engineering. Its activities range from digital libraries to knowledge networks to virtual educational structures.

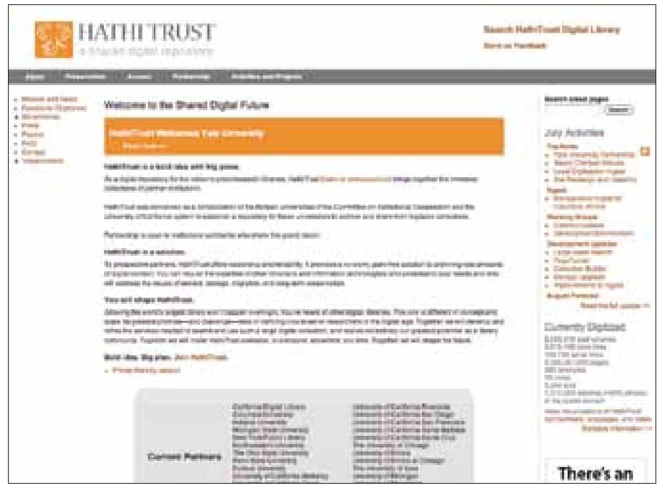
Although initially launched as graduate programs at the M.S. and Ph.D. level, the School of Information broaden in later years to also offer undergraduate degrees.

In 1996 the University created a new institution, the Michigan Virtual Auto College, designed to explore the implications of digital technology for higher education. This was a collaborative effort among the University of Michigan, Michigan State University, the State of Michigan, the state's other colleges and universities, and the automobile industry. It was formed as a private, not-for-profit, 501(c)3 corporation to broker technology-enhanced courses and training programs for the automobile industry, including the Big 3 and Tier 1, 2, and 3 providers.

The MVAC served as an interface between higher education institutions, training providers, and the automotive industry. It worked to facilitate the transfer of credits between and among institutions to facilitate certificate and degree attainment for those participating in courses and training programs offered under its auspices. The MVAC offered courses and training programs, ranging from the advanced post-graduate education in engineering, computer technology, and business administration to entry level instruction in communications, mathematics, and computers. Capitalization for MVAC was provided by members of the partnership: the State of Michigan ($5 million), the universities ($2 million), and the automobile industry ($5 million). However it is expected that the effort will rapidly become self-supporting, based on student fees. The schedule for the MVAC was an aggressive one, with formal incorporation in fall of 1996, delivery of the first array of pilot courses by February, 1997 and a full curriculum in place by Fall of 1997.

The MVAC paradigm was sufficiently successful

Google Books



Hathi Trust

that it broadened its curriculum into a full range of undergraduate curricula and was renamed the Michigan Virtual University in 1998, with participation by both public universities and community colleges throughout the state.

2000

During the 1990s, Michigan had received grant from the National Science Foundation to develop the technology for digital libraries. The University already had the experience of building the JSTOR library of the Mellon Foundation for digital archiving and providing access to scholarly work in history and economics. Among the students working on this project was a young Michigan computer engineering student named Larry Page went on to graduate school at Stanford (also part of the NSF digital library project), where he and Serge Brin developed the Page-Rank algorithm that was the key to the Google search engine.

In 2004 Page returned to Michigan and offered to have Google digitize our entire library (all 8 million volumes), which would become the nucleus of a major book search service by Google, now up to over 22 million volumes. Michigan went beyond to lead a group of universities (60 thus far) in pooling digital collections to create the Hathi Trust ("Hathi" means "elephant" in Hindi), adding over 400,000 books a month to form the nucleus (already at 14 million books, with 4 million of these already open for full online access) of what could become a 21st century analog to the ancient Library of Alexandria. While many copyright issues still need to be addressed, it is likely that these massive digitization efforts will be able to provide full text access to a significant fraction of the world's written materials to scholars and students throughout the world within a decade. Michigan has also played an important role in opening up access to both scholarly publications and digital archives critical to the advancement of knowledge in an increasingly digital world.

Michigan has provided leadership in developing sophisticated course managements systems with its Sakai software, now serving as the learning system for several major universities and supporting the CTools system at the University.

Concerns for the Future

The primary missions of the University, its teaching, research, and service activities (or alternatively, its activities of learning, discovery, and engagement with society) are increasingly dependent on cyberinfrastructure, i.e., information and communications technology. The rapid advances in these technologies are not only reshaping but creating entirely new paradigms for research, education, and application not only in science and engineering but in all of the academic and professional disciplines. It has been clear for sometime that to maintain world-class academic programs, the University must also achieve leadership in the quality and relevance of the cyberinfrastructure it provides at the level of each of its

Student computer teams working in the Duderstadt

UM hosted NSF meeting on cyberinfrastructure

highly diverse teaching and research programs.

This is particularly challenging since the features of information technology such as processing speed, memory, and bandwidth, have been increasing in power at rates of 100 to 1,000 fold per decade since WWII. This is one of the major reasons for the continued surprises we get from the emergence of new applications–the Internet, social networks, big data, machine learning–appearing in unexpected ways at a hyper exponential pace. We have learned time and time again that it makes little sense to simply extrapolate the present into the future to predict or even understand the next "tech turn". These are not only highly disruptive technologies, but they are highly unpredictable. Ten years ago nobody would have imagined Google, Facebook, Twitter, etc., and today, nobody really can predict what will be a dominant technology even five years ahead, much less ten!

Fortunately, the University of Michigan has been able to respond to such rapid technological change in the past–and, indeed, achieved leadership–because it has functioned as a loosely coupled adaptive system with many of our academic units given not only the freedom, but also the encouragement, to experiment and to try new things. It is at the level of academic units rather than the enterprise level where innovation and leadership must occur. Why? Because they are driven by learning and discovery, by experimentation, by tolerance for failure, and by extraordinarily talented faculty, students, and particularly, staff. While perhaps locating a computing cluster in every closet is not very efficient, it has made MIT, Carnegie Mellon, and Stanford leaders, as well as Michigan with CAEN and MERIT (i.e., NSFnet and then the Internet).

At a recent NSF sponsored conference on the role of cyberinfrastructure in discovery and learning hosted by the University, many participants stressed the importance of "craft", of the contributions of truly talented staff who drive innovation in units where they are most competent (Atkins, 2013). These people are attracted to universities such as Michigan to work in academic units with faculty and students where they are highly valued and have the freedom to do exciting work. In fact, its great strength and contribution to society arises from this very unusual diversity in ideas, experiences, and people. Again, this argues for an organic plan, essentially a diverse ecosystem that will continue to mutate and evolve in ways that we cannot anticipate.

In the past, the University has intentionally avoided the dangers of centralizing these activities, although every once in awhile the central administration will launch attempts to centralize what is inherently a highly decentralized technology. Most recently the University has retained Accenture to impose an "IT rationalization" scheme that would attempt to shift Michigan to a centralized IT services relying on commodity products and cloud services, largely crippling innovation in instructional and research activities. While such practices can be cost-effective in the corporate world (and perhaps in University business and hospital operations), they can be not only highly constraining but disastrous for teaching and research and must be strongly resisted.

The tension between centralization (whether MTS or "rationalization") and decentralization (where cacophony leads to innovation) can be very threatening, particularly to those parts of the University that need to make the trains run on time (e.g., financial services, hospitals, etc.) Fortunately, in the past, the wisdom of maintaining a loosely coupled adaptive system at the academic level finally bubbles up to the leadership of the institution, and academic units are set free once again. To be sure, the University has important responsibilities that require mission critical computing. But it is at the level of academic units rather than the enterprise level where innovation and leadership must occur. Why? Because they are driven by learning and discovery, by experimentation, by tolerance for failure, and by extraordinarily talented faculty, students, and particularly, staff.

Just what purposes should drive IT strategy. To support the university mission? What mission? Of the University writ large? Of the academic units? Of generic language like teaching, research, and service… or discovery, learning, and engagement…or "Change the world!"…or what?

Should academic institutions attempt to centralize all IT commodity services? In a loosely coupled adaptive system, one may need a more evolutionary system to do this, which taps bottom-up rather than top-down perspectives. (Look at the number of faculty in medicine who bring Macs to meetings when their Medical Center "employer" demands Windows machines as commodities…)

What should be the focus on solutions that are easily created and replaced? Agility to be sure. But what about resilience? And maturity? What about "optimum redundancy", so important to academic processes. For example, while we have committed at the enterprise level to Google, this is a company that still has not grown up yet to understand much less embrace "mission critical" applications such as university instruction. We need to be careful about becoming overly dependent on adolescents (at least it so appears from my visit to the GooglePlex.

Who should the University regard as priorities for IT services? Students? Faculty? Staff? Administrators? New learning paradigms such as blended education; experiential, personalized learning. Actually, all of this stuff has been part of the university's portfolio since the 19th century! Even the massive markets enabled by MOOCs is not really new. UM TV was teaching courses for credit with over 100,000 students through live TV in the early 1950s.

What is the appropriate strategy for enterprise-wide IT development? Most of the University's IT Strategic Plan is aimed at providing a cyberinfrastructure environment on campus. But the anyplace-anytime character of today's world leaves hanging the majority of the time spent working by our students, faculty, and staff, which is off campus in their homes, dorms, cars, wherever. Without a major plan for high-speed connectivity throughout the community, this is a very incomplete strategy. Most of the strategic investments associated with the NextGen infrastructure seem to be focused on-campus…WiFi networks, high capacity networks in data centers, labs, etc., use of clouds. But most of the time our people (faculty, students, staff) will be tethered to our resources through 4 MB/s cable or telcom carriers. Hence, without robust connectivity beyond the campus, these major investments will fall far short of our needs.

And how can centralization of the cyber experience handle the extraordinary diversity of the academic programs. The university in general–and Michigan in particular–is one of the most intellectual diverse organizations in the world. In fact, its great strength and contribution to society arises from this very unusual diversity in ideas, experiences, and people. Again, this argues for a much more organic plan, essentially a diverse ecosystem that will continue to mutate and evolve in ways that we cannot anticipate.

As an example, the learning paradigm varies enormously across campus, from the general education of young students to disciplinary concentrations (compare deconstructing a poem with proving a theorem in algebraic topology) to professional education (operating on a patient or arguing a case before a court or building and testing a drone design). Too much of centralized strategy is focused on undergraduate education as if we were primarily a "college". We're not! We're one of the world's great "universities", and that is quite a different intellectual entity. Again, "seamless learning", "emerging learning modalities", etc., are not only buzz words but sound more appropriate for young K-12 learners than for the *Universitas Magistrorum et Scholarium* that characterizes one of the world's great research universities.

Where is the subject of institutional collaboration? Today our faculty work more with colleagues on the other side of the globe than across the hall; our students bring multi-institution study groups with them from their high school days…and Facebook, of course…most of our faculty are nomadic, moving from institution to institution every few years, just as our students will move on to other endeavors and institutions when they finish their studies. Again, more consideration needs to be given of life beyond the campus...and with institutions beyond our own.

Too much of the current focus is shaped by today's technologies, not tomorrows. Cloud services, big data, analytics. Again, overdependence on commodity products, particularly to the degree we constrain the cyber environments of academic units through policies such as purchasing and shared services, will harm the loosely coupled adaptive culture of the university that is one of our greatest strengths. This is particularly dangerous if we become overly dependent on particular vendors because of top-down rather than bottom-up forces. The reality is (and always has been) that it has been our faculty, staff, and students who spot the next big trends in technology and then drive change upward through the institution.

It is becoming increasingly clear that we are approaching an inflection point in the potential of rapidly evolving information and communications technology to transform how the scientific and engineering enterprise does knowledge work, the nature of the problems it undertakes, and the broadening of those able to participate in research activities.

Of course, the impact of rapidly evolving cyberinfrastructure on research and scholarship has been experienced across not only all of the academic disciplines (e.g., the natural and social sciences and the arts and humanities), but throughout the professional disciplines as well. New paradigms are rapidly emerging as well for learning and education as well as innovation and professional practice such as Massively Open Online Courses (MOOCs), open learning initiatives, and immersive learning environments (including immersive gaming). The challenge for discovery and learning is to use cyberinfrastructure as a platform for enhancing knowledge communities and for expanding their scope and participation unconstrained by time and distance by stressing the interconnection between learning about, learning to do, and learning to be, eventually becoming a member of a community of practice.

To quote Arden Bement, former NSF Director, "We are entering a second revolution in information technology, one that may well usher in a new technological age that will dwarf, in sheer transformational scope and power, anything we have yet experienced in the current information age" (Bement, 2007). The implications of such rapidly evolving technology for the future of the discovery, innovation, and learning are of great importance to the prosperity, health, and security of our nation as it faces the challenge of an increasingly knowledge- and innovation-driven world. Such cyberinfrastructure will not only be increasingly important to higher education, but it will drive the evolution of the university as a knowledge institution.

A brief history of "computing"at UM and some lessons learned from it. Interplay between innovation in technology development, broad adoption, and meaningful use in service of UM mission. (Atkins, 2018)

I. UM IT History Project

1881 - Installed first telephone, five years after Bell invention. (An act of the Regents).
1901 - First EE course on telephone and telegraph
903 - Broadcast UM-Minnesota football game to AA residents via phone
1907 - May Festival orchestra concert broadcast to Detroit
1912 - The two separate telephone companies in AA merged ending the need to support two different, non- interoperable systems.
1929 - Change to a dial system
1934 - 1400 telephones on campus
Early telephone era
1919 - Purchased first key punch machines and began use for admin work

2. Tabulators and analog computers

1920-1925 UM President Marion Burton
1925-1929 UM President Clarence Little
1929-1951 UM President Alexander Ruthvan
1930 - Began routine use of tabulator machines in Registrar'sOffice and Hospital
1949 - Analog computers introduced in instruction in aerospace Engineering (Prof. Bob Howe)
1951-1967 UM President Harlan Hatcher
b) 1951-1958 UMs first digital computer, MIDAC, developed and used.
c) 1953-1963 College of Engineering offers intensive short courses for scientists and engineers attended by people cross the country. (Profs Carnahan & Wilkes)
d) 1954 - UM processed 2 million punch cards for the field trials for Salk polio vaccine
e) 1956 - Prof. Art Burks founded Logic of Computers group
f) 1957 - Communication Sciences grad program established in LSA. Later became a department and in early 1980s merged into EECS in Engineering. UG LSA program contines
1957 - EE Dept begins courses on digital computer design and application

3. 1950s

1959-1963 Ford Foundation funds UM to lead national initiative in computing use in undergrad engineering.
1959 - Acquired IBM 650 then IBM 704
1959 - Computing Center established under Graduate School. Later moved to OVPR.
1962 - ICPR established as social science data archives used by many universities. Continues as a leader today.
1965 - NSF funds "Computers in Engineering Education" grant at UM
1966 - MERIT computer network established between UM, MSU and Wayne State. (Three years before ARPANet.
1968-1979 UM President Robben Fleming
1969 - ARPA Net (precursor of Internet) sends first message

4. 1970s

1971 - Computing Center moves to North Campus
1972 - Prof. Bennie Galler & students develop CRISP, class registration system
1973 - One of the first Computer Engineering degrees established.
1975 - PhD Student Bob Parnes develops CONFER, a pioneering conferencing system. The first "social media."

5. 1980s

1980-1987 UM President Harold Shapiro
1981 - UM widely adopts routine use of home grown email system call MESSAGE
1983 - College of Engineering launches Computer Aided Engineering Network (CAEN) to begin distributed computing era at UM (Duderstadt & Atkins)
1984 - UM begins R&D around digital libraries with supportfrom NSF and industry. (Atkins,

et.al). This work enabled later leadership by UM in piloting the Mellon JSTOR Project and UM leadership role in Google Books Project.

1985 - UM pioneers the concept of a "research collaboratory" - a laboratory without walls. Over a decade of sponsored research by NSF. A by product of software developed with CTools course management and project coordination system. (Atkins, et. al)

1984 - Doug Van Houweling becomes first Vice Provost for IT

1985 - Formation of Information Technology Division (ITD)

1985 - Large investment in fiber optic plant and extension of network to residence halls

1985 - First and largest ever MacIntosh "Truck Load Sale". Frequent interactions with Steve Jobs.

1985 - Institutional shared file system developed and deployed

1986 - Installation of new digital telephone switch with 27,000 lines

l987 - UM MERIT team wins NSF award to establish and operate NSFNET to open Internet capability to all of higher ed. The explosive growth of NSF played a major role in the dominance of TCP/IP as the universal Internet protocol.

1988-1996 UM President James Duderstadt

1988 - MIRLYN computerized library catalog system launched

1989 - Angell Hall courtyard converted into computing access cluster

1989 - UM Library established Internet-based access to

arge text corporate (pre-Web, used X-Windows based browser and custom terminal-based application)

6. 1990s

1990 - Emergency phone system installed on campus

1990 - Tim Berners-Lee at CERN completes all the tools necessary for a working WWW.

1991 - NSFNET operated by UM was spun off to Advanced Network Services to enable both non-profit and commercial development.

1993 - Mosaic browser becomes widely available and enables explosion of WWW usage.

1993 - NSF Digital Library Initiative begun. UM was one of six major awards. The DLI also supported UM grad Larry Page (then at Stanford) on a research project that led to the core web page ranking technology for Google.

1994 - Wolverine Access launched and Library launched Humanities Test Initiative

1995 - Program for the Study of Complex Systems established

1996 - Jose-Marie Griffiths named director of new Information Technology Division (ITD)

1996 - UM adopts PeopleSoft client/server system for admin computing

1996 - UM Library Making of America project launched. http://quod.lib.umich.edu/m/moagrp/

1996 - UM leaders launch the Internet 2 project with 34 universities. Became a separate non-profit in 1997 with an administrative services support relationship with UM.

1996 - UM establishes the first School of Information

1997 - TULIP and later PEAK project between UM and Elsevier helped establish economic models for digital publishing and the field of digital information economics. (Mackie-Mason, et.aln)

1996-2001 UM President Lee Bollinger

1998 - UM pilots JSTOR Project with funding from Mellon Foundation. http://www.jstor.org

7. 2000s

2001 - James Hilton appointed Associate Provost for Academic Information and Instructional Technology Affairs

2002-2014 UM President Mary Sue Coleman

2003 - NSF issues major report Revolutionizing Scienceand Engineering Through Cyberinfrastructure

2004 - UM launches Google Books project (https://www.google.com/googlebooks/library/)

2006 - Deep Blue digital repository launched

2006 - Prof. John King appointed VP for Academic Information. ITS and ICS merged.

2008 - UM leads establishment of HathiTrust (https://www.hathitrust.org)

2008 - Formation of Office of Research Cyberinfrastructure (ORCI) reports to Provost and VPR in partnership with ITS.(Atkins). FLUX facility established.

2009 - Laura Patterson appointed Chief Information Officer and Associate Vice President for Information and Technology Services (ITS)

2010 - IT Council formed with IT investment prioritization based on mission-driven emphasis and multi-stake holder perspectives.

2012 - ORCI evolves into ARC under leadership of Prof. Eric Michielssen. Continued enhancement of infrastructure plus major programmatic initiatives (MICDE, MIDAS, expanded CSAR.) Has brought national recognition and praise.

2013 - James Hilton appointed Dean of Libraries and Vice Provost for Digital Educational Initiatives

2014 - UM President Mark Schlissel

Appendix C

The University of Michigan's Impact on IT Policy Development

Higher education has entered a period of significant change as our universities attempt to respond to the challenges, opportunities, and responsibilities facing them in the new century. The forces driving change are many and varied: the globalization of commerce and culture, the advanced educational needs of citizens in a knowledge-driven global economy, the exponential growth of new knowledge and new disciplines, and the compressed timescales and nonlinear nature of the transfer of knowledge from campus laboratories into commercial products. We are in a transition period where intellectual capital is replacing financial and physical capital as the key to prosperity and social well being. In a very real sense, we are entering a new age, an age of knowledge, in which the key strategic resource necessary for prosperity has become knowledge itself, that is, educated people and their ideas.

Our rapid evolution into a knowledge-based, global society has been driven in part by the emergence of powerful new information technologies such as digital computers and communications networks. Modern digital technologies have vastly increased our capacity to know and to do things and to communicate and collaborate with others. They allow us to transmit information quickly and widely, linking distant places and diverse areas of endeavor in productive new ways. This technology allows us to form and sustain communities for work, play, and learning in ways unimaginable just a decade ago. It has broadened access to knowledge, learning, and scholarship to millions throughout the world. Information technology changes the relationship between people and knowledge. It is likely to reshape in profound ways knowledge-based institutions such as our colleges and universities.

Of course higher education has already experienced significant change driven by digital technology. Our management and administrative processes are heavily dependent upon this technology. Research and scholarship are also highly dependent upon information technology, for example, the use of computers to simulate physical phenomena, networks to link investigators in virtual laboratories or "collaboratories," and digital libraries to provide scholars with access to knowledge resources. There is an increasing sense that new technology will also have a profound impact on teaching, freeing the classroom from the constraints of space and time and enriching learning by providing our students with access to original source materials.

Yet, while information technology has the capacity to enhance and enrich teaching and scholarship, it also poses certain threats to our colleges and universities. We can now use powerful computers and networks to deliver educational services to anyone, anyplace, anytime, no longer confined to the campus or the academic schedule. Technology is creating an open learning environment in which the student has evolved into an active learner and consumer of educational services. Faculty loyalty is shifting from campus communities and universities to scholarly communities distributed in cyberspace. The increasing demand for advanced education and research from a knowledge-driven society, the appearance of new for-profit competitors, and technological innovations are stimulating the growth of powerful market forces that could dramatically reshape the higher education enterprise.

Preparing for the Revolution

Reflecting their broad interest in the health of America's research enterprise, the National Academies launched a study in early 2000 on the implications of

PANEL ON THE IMPACT OF INFORMATION TECHNOLOGY ON THE FUTURE OF THE RESEARCH UNIVERSITY

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JOHN SEELY BROWN, Chief Scientist, Xerox Corporation
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RALPH E. GOMORY, President, Alfred P. Sloan Foundation
NILS HASSELMO, President, Association of American Universities
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SHIRLEY ANN JACKSON, President, Rensselaer Polytechnic Institute
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MARSHALL S. SMITH, Professor, School of Education, Stanford University and Program Officer for Education, Hewlett Foundation
LEE SPROULL, Professor, Leonard N. Stern School of Business, New York University
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ROBERT WEISBUCH, President, Woodrow Wilson National Fellowship Foundation
WM. A. WULF, President, National Academy of Engineering
JOE B. WYATT, Chancellor Emeritus, Vanderbilt University

Principal Study Staff:

RAYMOND E. FORNES, Visiting Senior Scientist/Study Director, and Professor of Physics, North Carolina State University (on sabbatical during 2000-2001)

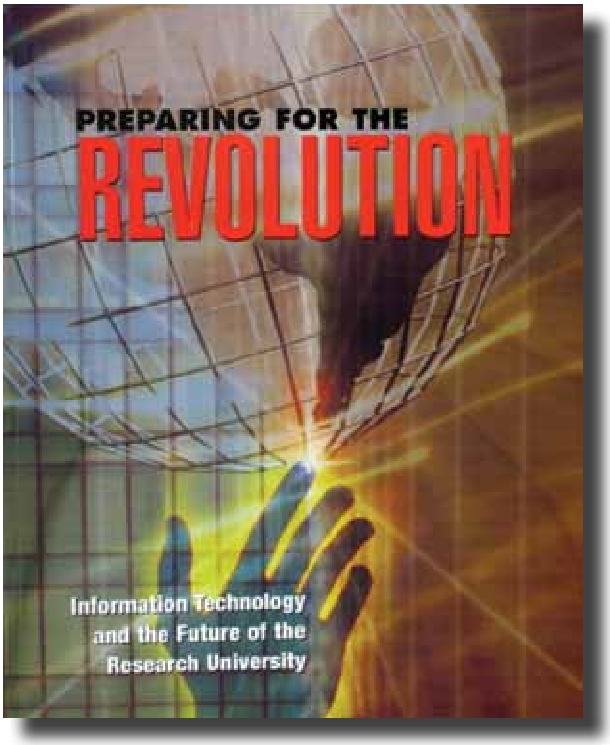
Roundtable discussions with university leaders

information technology for the future of the nation's research university—a social institution of great importance to our economic strength, national security, and quality of life. The premise of this study was a simple one. Although the rapid evolution of digital technology will present numerous challenges and opportunities to the research university, there is a sense that many of the most significant issues are not well understood by academic administrators, faculty, and those who support or depend on the institution's activities.

The steering group for the effort was comprised of leaders from higher education, the chief technology officers of major IT companies, and leaders in national science policy. This group met on numerous occasions over a two-year period to consider these issues, including site visits to major technology laboratories such as Bell Labs and IBM Research Labs and drawing upon the expertise of the National Academy complex. At the end of this period, over one hundred leaders from higher education, the IT industry, and the federal government, and several private foundations convened for a two-day workshop at the National Academy of Sciences to focus this discussion. Beyond the insight brought by these participants, perhaps even more striking was their agreement on a number of key issues.

The first finding was that the extraordinary pace of information-technology evolution is likely to continue for the next several decades, possibly even accelerating. Hence, in thinking about changes to the university, one must think about the technology that will be available in 10 or 20 years, technology that will be thousands of times more powerful as well as thousands of times cheaper. The second finding was that the impact of IT on the university is likely to be profound, rapid, and disruptive, affecting all of its activities (teaching, research, service), its organization (academic structure, faculty culture, financing, and management), and the broader higher education enterprise as it evolves toward a global knowledge and learning industry. If change is gradual, there will be time to adapt gracefully, but that is not the history of disruptive technologies. As Clayton Christensen explains in *The Innovators Dilemma*, new technologies are at first inadequate to displace existing technology in existing applications, but they later explosively displace the application as they enable a new way of satisfying the underlying need.

While it may be difficult to imagine today's digital technology replacing human teachers, as the power of this technology continues to evolve 100- to 1000-fold each decade, the capacity to reproduce all aspects of



DOE Task Force Report

human interactions at a distance with arbitrarily high fidelity could well eliminate the classroom and perhaps even the campus as the location of learning. Access to the accumulated knowledge of our civilization through digital libraries and networks, not to mention massive repositories of scientific data from remote instruments such as astronomical observatories or high energy physics accelerators, is changing the nature of scholarship and collaboration in very fundamental ways.

The third finding stresses that although information technology will present many complex challenges and opportunities to universities, procrastination and inaction are the most dangerous courses to follow all during a time of rapid technological change. Attempting to cling to the status quo is a decision in itself, perhaps of momentous consequence.

The first phase of this study, its conclusions, and its recommendations were published in a report, Preparing for the Revolution, available both online and through hard copy from the National Academies Press.

The IT Forum

In 2003 the National Academies have extended this effort to involve directly a large number of research universities by creating a National Academy roundtable on information technology and research universities ("the IT-Forum") to track the technology, identify the key issues, and raise awareness of the challenges and opportunities. The IT Forum has also conducted a series of workshops for university presidents and chief academic officers in an effort to help them understand better the transformational nature of these technologies and the importance of developing strategic visions for the future of their institutions.

The IT Forum began its activities in spring of 2003 with a two-day workshop involving two dozen leaders of major research universities at the spring meeting of the Association of American Universities (AAU). To launch the discussion, Louis Gerstner, CEO of IBM, spoke at a dinner meeting the evening before the workshop to share with the presidents some of his own observations concerning leadership during a period of rapid change. The IBM experience demonstrated the dangers of resting on past successes. Instead, leaders need to view information technology as a powerful tool capable of driving a process of strategic change, but only with the full attention and engagement of executive leadership–meaning university presidents themselves.

Noting that university presidents listen most carefully to their own voices, the workshop was organized about several panels of the participating presidents. The first panel was asked to discuss what was currently in their in-out box, the here-and-now issues. These included the usual concerns such as how to meet the seemingly insatiable demand for computing resources (particularly bandwidth), how to pay for this technology, and how to handle privacy and security issues. It is probably no surprise that that most of the presidents believed that they had these issues well in hand–a perception quite different than we were to find with their provosts several months later.

Members of the IT Forum then attempted to move the discussion farther into the future and elevate it to a more strategic level by posing a number of provocative possibilities to the presidents. For example, how would adapt their library planning to the very real possibility that within a decade, the entire Library of Congress (about 10 TB) could be contained in a

IT Forum Participants

IT Forum Meetings

consumer device about the size of a football (a size university presidents understand well)–or more to the point of students, an iPod? How would the rapid evolution of cyberinfrastructure–the hardware, software, organizations, people, and policy increasing undergirding scientific research–into functionally complete environments for scholarship and learning affect their faculty and students? What if their students utilized IT to take control of their learning environments? These rhetorical hand-grenades triggered a broader discussion of related concerns such as the technological generation gap among students and faculty, the disruptive force of the marketplace brought onto campus by IT, and the disaggregation and reaggregation of the traditional roles and functions of the university.

As the discussions moved on to consider increasingly unpredictable futures, there was a growing recognition of the challenge of providing leadership in the face of such uncertain futures. Finally one of the presidents suggested that he had no idea how presidents were to lead in such a chaotic environment, and that he and his colleagues needed help. Hence, the workshop had managed to bring the presidents through several critical stages: from denial to acceptance to bargaining to seeking help…

The IT Forum followed several months later with a very similar workshop for the provosts of AAU research universities. Again the session began by first asking a panel of provosts to lay out the issues as they saw them at the moment, then to move the discussion to a longer-term perspective, and finally to conclude with a discussions of next steps. The near-term concerns of the provosts were very similar to those of the presidents: network and bandwidth manage, the financing of technology, the protection of security and privacy, and data management and preservation.

Perhaps not surprising was a far greater degree of sophistication among the provosts in understanding and addressing these issues than shown by the presidents, perhaps since as chief academic officers, they were on the front line. But here there was an even more significant difference: unlike the presidents, the provosts recognized (or at least admitted) that these were very difficult issues and that they certainly did not have the answers. The provosts also were willing to discuss issues that would require major cultural changes in their institutions. For example, they expressed growing concern about the degree to which universities were being disadvantaged by the effective monopolies created by IT providers. As one provost put it, universities acted like deer paralyzed in the oncoming headlights, continuing to re-invent the wheel and getting devoured by the marketplace. The provosts were essentially unanimous in their belief that it was time for the universities to set aside their competitive instincts and to build consortia to develop together the technologies to support their instructional, research, and administrative needs through open-source paradigms that would break the stranglehold of the current IT marketplace.

Many provosts suspected that while the faculty believed they knew how their students learned, in reality they had not a clue, particularly in technology-rich environments. This was a theme we were to encounter again and again in our later workshops. The provosts believed that their universities needed far more sophisticated help to understand the learning and cognitive processes characterizing contemporary students, although they also recognized the disruptive nature of these studies which might eliminate over time the rationale for the lecture-classroom paradigm.

In-Depth Meetings

To explore in depth several of the issues raised in the workshops with presidents and provosts, the IT Forum arranged several more focused site visits:

IT-Forum Meeting on "Cognition, Communication, and Communities"
Carnegie-Mellon University (September 5-6, 2003)

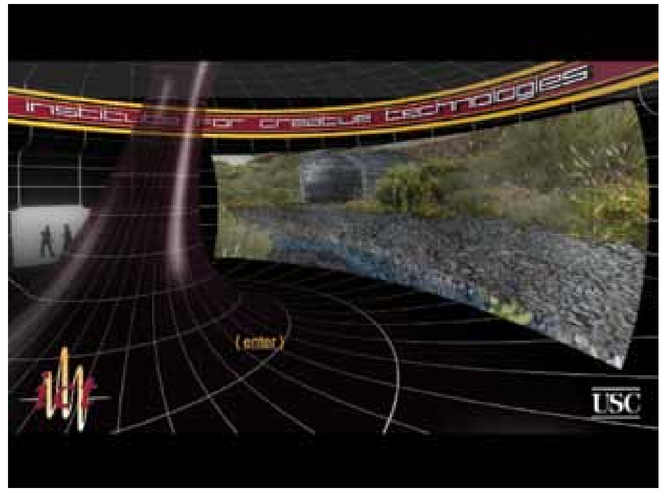
To learn more about how learning occurs in technology-intensive environments, the IT Forum held its fall 2003 meeting at Carnegie Mellon University, renown both as one of the nation's most wired—and now wireless—campuses and also for its strength in the cognitive sciences. As the CMU faculty put it, their students have embraced IT to become a transformative force, frequently forcing the faculty to react to their learning styles and activities. An example is the way students use this technology for communication. From instant messaging to e-mail to blogs, students are in continual communication with one another, forming learning communities that are always interacting, even in classes (as any faculty member who has been "Googled" can attest). A young professor of physics told us he had been forced to give up trying to teach difficult concepts in his classes. Instead he introduces a topic by pointing to several resources until a few students in the class figure out a way to teach themselves the concept. Then they teach their fellow students, and through peer-to-peer learning, the concepts propagate rapid through the class.

Today's students are active learners, building their own knowledge structures and learning environments through interaction and collaboration. Their approach to learning is highly nonlinear rather than following the sequential structure of the typical university curriculum. They are adept at multitasking and context switching. And they are challenging the faculty to shift their instructional efforts from the development and presentation of content, which is more readily accessible through the web and open-content efforts such as the Open CourseWare initiative of MIT, and instead become more of a mentor and consultant to student learning.

Some CMU faculty members have concluded that perhaps the best approach in these technology-rich environments is to turn the students loose, letting them define their own learning environments. Peer-to-peer learning is rapidly replacing faculty teaching as the dominant educational process on this technology-rich campus. There is not yet a consensus among the faculty as to where they are headed, but there is strong agreement that the net generation is both challenging and changing the learning process in very fundamental ways.

On a deeper level, information technology is forcing us to rethink the nature of literacy: From literacy in the oral tradition…to the written word…to the images of film and then television…to the computer and multimedia. Of course there are many other forms of literacy: art, poetry, mathematics, science itself, etc. But more significantly, the real transformation is

John Seely Brown at Carnegie Mellon



Institute for Scientific Computation USC

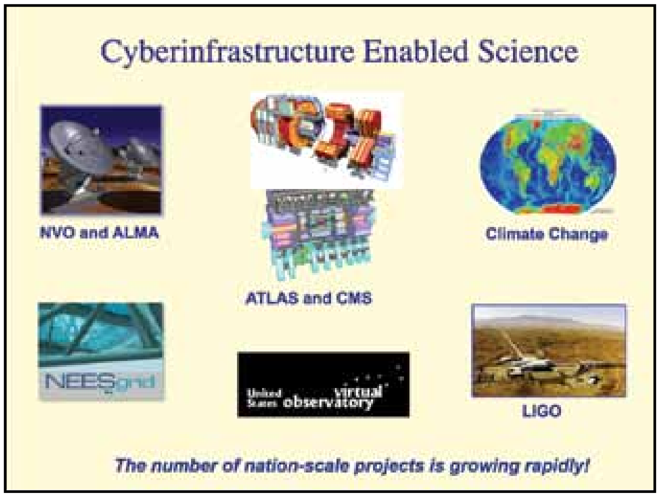
Chuck Vest at MIT

MIT Meeting

National Academy of Sciences

University of Michigan

Meetings of the IT Forum



from literacy as "read only, listening, and viewing" to composition in first rhetoric, then writing, and now in multimedia.

Increasingly, we realize that learning occurs not simply through study and contemplation but through the active discovery and application of knowledge. From John Dewey to Jean Piaget to Seymour Papert, we have ample evidence that most students learn best through inquiry-based or "constructionist" learning. As the ancient Chinese proverb suggests "I hear and I forget; I see and I remember; I do and I understand." To which we might add, "I teach and I master!!!"

IT Forum Meeting on "Virtual Worlds" at The Institute for Creative Technologies, Marina del Rey (March 11, 2004)

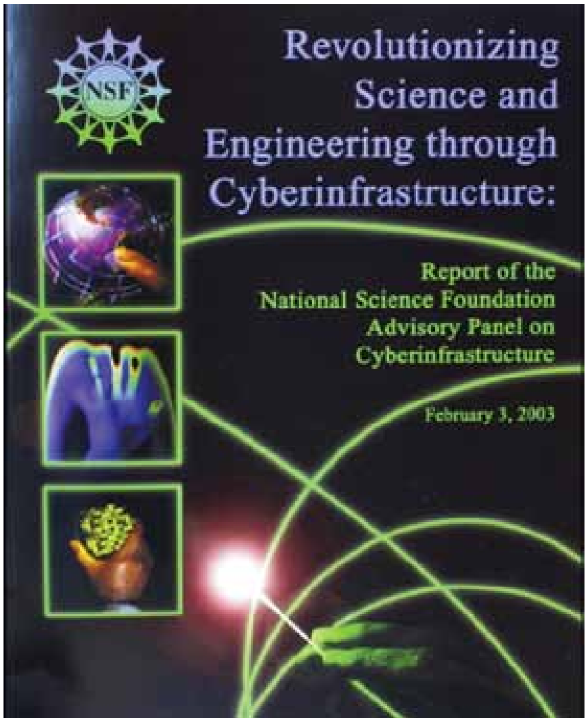
To understand new paradigms of technology-assisted learning, the spring 2004 meeting of the IT-Forum was held at the Institute for Creative Technologies in Marina del Rey. Here, the University of Southern California is applying the entertainment and gaming technologies developed by Hollywood and others to create a "holodeck" to train military officers in high level cognitive activities such decision making and leadership. They have learned something that universities have yet to grasp: how technology can be used to create an emotional connection between knowledge and learning.

IT-Forum Meeting on "Cyberinfrastructure" at University of Michigan, Ann Arbor (November 11-12, 2004)

In fall of 2004, the IT Forum met at the University of Michigan to consider the important study by the National Science Foundation Blue Ribbon Advisory Panel on Cyberinfrastructure.

Here "cyberinfrastructure" is the term used to describe hardware, software, ,people, organizations and policies related to information and communications technology. The panel concluded that we are approaching an inflection point in the potential of rapidly evolving information and communications technology to transform how the scientific and engineering enterprise does knowledge work, the nature of the problems it undertakes, and the broadening of those able to participate in research and the related educational activities. To quote the concluding paragraph of its report:

"A new age has dawned in scientific and engineering research, pushed by continuing progress in computing, information, and communication technology, and pulled by the expanding complexity, scope, and scale of today's challenges. The capacity of this technology has crossed thresholds that now make possible a comprehensive 'cyberinfrastructure' on which to build new types of scientific and engineering knowledge environments and organizations and to pursue research in new ways and with increased efficacy. Increasingly, new types of scientific organizations and support environments for science are essential, not optional, to the aspirations of research communities



Atkins Report on Cyberinfrastructure

and to broadening participation in those communities. They can serve individuals, teams, and organizations in ways that revolutionize what they can do, how they do it, and who participates. This vision has profound broader implications for education, commerce, and social good."

Clearly, cyberinfrastructure is not only reshaping but actually creating new paradigms for science and engineering research, training, and application. Once the microprocessor was imbedded in instrumentation, Moore's Law took over scientific investigation. The availability of powerful new tools such as computer simulation, massive data repositories, massively ubiquitous sensor arrays, and high-bandwidth communication are allowing scientists and engineers to shift their intellectual activities from the routine analysis of data to the creativity and imagination to ask entirely new questions. Today, information technology has created, in effect, a new modality of scientific investigation through simulation of natural phenomenon and serving as the bridge between experimental observation and theoretical interpretation. Globalization is a particularly important consequence of the new forms of scientific collaboration enabled by cyberinfrastructure, which is allowing scientific collaboration and investigation to become increasingly decoupled from traditional organizations (e.g., research universities and corporate R&D laboratories) as new communities for scholarly collaboration evolve.

While promising significant new opportunities for scientific and engineering research and education, the digital revolution will also pose considerable challenges and drive profound transformations in existing organizations such as universities, national and corporate research laboratories, and funding agencies. Here it is important to recognize that the implementation of such new technologies involve social and organizational issues as much as they do technology itself. Achieving the benefits of IT investments will require the co-evolution of technology, human behavior, and organizations.

Although the domain-specific scholarly communities, operating through the traditional bottom-up process of investigator-proposed projects, should play the lead role in responding to the opportunities and challenges of new IT-enabled research and education, there is a clear need to involve and stimulate as well those organizations that span disciplinary lines and integrate scholarship and learning. Perhaps the most important such organization is the research university, which despite the potential of new organizational structures, will continue to be the primary institution for educating, developing, and financing the American scientific and engineering enterprise. Furthermore, because the contemporary research university not only spans the full range of academic disciplines but as well as the multiple missions of education, scholarship, and service to society, it can–indeed, it must–serve as the primary source of the threads that stitch together the various domain-focused efforts.

There is a sense among many in the research university community that we will see a convergence and standardization of the cyberinfrastructure necessary for state-of-the-art research and learning over the next several years, built upon open source technologies, standards, and protocols, and that the research universities themselves will play a leadership role in creating these technologies, much as they have in the past. For the IT-driven transformation of U.S. science and engineering to be successful, it must extend beyond the support of investigators and projects in domain-specific science and engineering research to include parallel efforts in stimulating institutional capacity.

National Science Foundation Tutorial

In fall of 2004, members of the IT Forum were invited to conduct a day-long "tutorial" for the leadership of the National Science Foundation concerning the potential impact of information technology on learning, broadly defined. Forum members began by stating their concern that the changing learning needs of our society and the disruptive nature of digital technology may extend well beyond the capacity of our existing learning infrastructure of schools, universities, training programs, and cultural institutions. Approaching the challenge by reforming existing institutions may not be sufficient. After all, "a butterfly is not simply a better caterpillar!" Instead perhaps it was time to explore entirely different types of learning organizations and ecologies.

Today the human resource needs of the nation, an increasingly competitive global, knowledge-driven economy, and the challenge and promise presented by exponentially evolving digital technology presents a new and compelling challenge to NSF to provide leadership and stimulate change in our nation's learning enterprise.

University Executive Leadership Core Workshops

One of the major concerns voiced in the workshops with the Association of American Universities presidents and provosts was the difficulty in getting universities to recognize the strategic implications of rapidly evolving digital technologies as they reshape the most fundamental aspects of learning and scholarship. Some participants portrayed the challenge to be getting the executive leadership core of the institution–the president, provost, CFO, CIO, director of libraries, key deans–on the same page, communicating with one another rather than simply dumping a diverse array of issues and demands on the CIO and saying, "Handle it!"

To this end they suggested that the IT Forum conduct a series of roundtable workshops around the country, bringing together the executive leadership of several institutions in a facilitated roundtable discussion to compare notes on what they saw as challenges and opportunities. The hope was that engaging in a candid and confidential discussion with peer institutions would force each of the participating teams to get their act together. They would learn from each other and perhaps develop the basis for further collaboration.

Over the course of the 2004-2005 academic year, the IT Forum organized four such workshops:

Cambridge (September 1-2, 2004): CEO-led teams from Carnegie-Mellon University, Cornell University, and Massachusetts Institute of Technology

Chapel Hill (January 24-25, 2005): CEO-led teams from North Carolina State University and the University of North Carolina at Chapel Hill, an Executive Vice Chancellor-led team from Duke University, and individual leaders from Georgia Institute of Technology and the University of Maryland

Austin (March 21-22, 2005): CEO-led teams from Texas A&M University, the University of Arizona, and the University of Texas at Austin, and individual leaders from Arizona State University and Rice University

Irvine (April 25-26, 2005): CEO-led teams from the University of California, San Diego, the University of California, Santa Barbara, and the University of Southern California, an Executive Vice Chancellor-led team from the University of California, Los Angeles, and an individual leader from the University of California, Irvine.

The purpose of these workshops were: i) to help university leadership identify the key challenges and opportunities presented by emerging information technology by comparing perspectives with several peer institutions; ii) to help the executive leadership of a university get on the same page in developing institutional strategies; and iii) to explore how to build stronger coalitions of universities working together to address these challenges.

The workshops were organized in a roundtable format developed by Robert Zemsky, former chair of the Pew Higher Education Roundtable and now director of the Learning Alliance at the University of Pennsylvania, who also served as the moderator for these sessions. Such a roundtable process is particularly effective in encouraging broad and candid engagement of all participants. Each workshop was launched with a working dinner the evening before a day-long workshop, asking each of the presidents to begin the conversation by describing what excited and what scared them about rapidly evolving digital technology. Needless to say, the fears tended to outnumber the hope.

Not surprisingly, several presidents immediately brought up the challenge of managing unbridled expectations for the IT environment. Their faculties believed that "bandwidth should flow like water from a faucet". These university leaders worried that they would be unable to afford the IT investments necessary to stay on the cutting edge of research while meeting ever-expanding student expectations and eventually fall behind, unable to compete for the best faculty and students. Several also expressed concern about the difficulty of making the right decisions on investments, e.g., knowing whether they were headed in the right direction or toward a wall (or a cliff). There was a sense of dread because of the uncertainty and the implications of a bad decision, in terms of cost, the quality of the environment or teaching and research, and even the ability of the institution to function. As one president put it, "I worry that one day I will come into work and find that absolutely nothing works."

Such concerns usually led rapidly to a discussion of the increasing challenge in maintaining the security of the IT infrastructure. Some participants even suggested that a failure in this area could lead to the entire enterprise grinding to a halt, or that a severe attack launched through a university and impacting broader society might result in civil or even criminal liability. Although several of the CIOs agreed that this problem was solvable with sufficient standards and controls, frequently these were incompatible with the diversity–indeed, anarchy–characterizing the many computing environments and student and faculty cultures in the university.

One of these evening dinner discussions was dominated by a conversation on the degree to which students were beginning to use technology both to seize control of their learning environments and to drive change within the institution, much as the IT Forum had found in the workshop at Carnegie-Mellon University. The student social life and learning activities were increasingly structured around always-on, always-in-contact communication (wireless, e-mail, instant messaging). In contrast to the student isolation that some predicted as a consequence of the propagation of technology into the university, there is a zeal for contact and community building among students, demanding not only an ever more sophisticated IT environment, but as well the convenience and responsiveness of university services and instructional activities that students were accustomed to in the commercial arena (Amazon, Google, e-Bay, Travelocity, etc.) Students were beginning to form communities capable of learning on their own and challenging the one faculty member-one course paradigm.

Yet at most institutions, these new IT-based social organizations were quite beyond the comprehension of the faculty, many of whom would just as soon ban wireless connectivity from the classroom and restrict students to using 110 bits-per-second modems to slow things down. While several participants questioned the effectiveness of this highly interactive, multi-tasking, and rapid context switching approach to learning, others suggested it might actually be the best preparation for leadership roles in the very complex, fast- moving social situations of 21st century society. Yet this not only raised the challenge of keeping up with the kids as they became less and less tolerant of traditional approaches to higher education, but it also raised the question of the role that the faculty would play, e.g., leading, lagging, or just staying out of the way.

Such discussions usually converged on recognition that the rapid evolution of digital technology was not only creating a very complex environment for leadership, but that it was characterized by chaos, in which the predictability of decisions and actions became very difficult if not impossible. Efforts to exert the top-down controls demanded by network security and integrity sometimes seemed like trying to close the barn door after the horse had not only already escaped, but the barn itself had fallen down. Several of these evening conversations even suggested that the traditional organization, structure, management, and leadership of the university might be inadequate to deal with such a rapidly evolving and changing technology. At this point, we usually called it an evening, and adjourned to the next day for more in-depth discussions of particular issues of interest to the participants.

Managing Change

The primary issue arising in discussions of managing the IT environment involved the balance between the centralized control and standardization necessary to achieve adequate connectivity and security, and the inevitable chaos that characterizes the university IT environment because of highly diverse needs and funding sources–particularly in the research arena. There needs to be a balance between infinite customizability and institution-wide standards that protect the organization. There is a need to tolerate freedom–indeed, anarchy–in some domains such as research, while demanding tight control and accountability in others such as telecommunications and financial operations. Of course, this is similar to the struggle between the centralization (security, interoperability) and the decentralization (creativity, unique needs) in all organizations–universities, governments, and corporations.

There was also considerable discussion of just where universities should focus their resources and attention. Some universities felt that the best approach was to outsource the stable infrastructure, including mission-critical services such as finance and telecommunications, and focus attention instead on advanced development efforts, particularly those involving consortia such as Open Knowledge Initiative and Sakai . It is important to select what you can manage, and what you can let go, to pick those areas where you can see strategic opportunities for influence. Outsourcing commodity products and services can allow institutions to free up resources for investing in the future.

Although some institutions were still striving for centralized control, most had recognized that heterogeneity was a fact of life that needed to be both tolerated and supported. It was important to move beyond the contrasts between academic and administrative IT and instead recognize the great diversity of needs among different missions such as instruction, research, and administration as well as among early adopters, mainstream users, and have-nots. The faculty seeks both a reliable platform (a utility) as well as the capacity to support specific needs; researchers would frequently just as soon the administration kept hands off, since their grants are paying for their IT support. The students seek the same robust connectivity and service-orientation that they have experienced in the commodity world, and they will increasingly bring the marketplace onto the campus. In some ways, executive leadership is less a decision issue than a customer relationship management issue.

Several of the workshops featured discussions about the most important IT-related decisions made in the past few years, what issues were involved, who was involved in discussion and decision-making, and what the results were. To our ears, these decisions mainly fell into two categories. The first consisted of seeming “no-brainers,” where it was necessary to get presidential approval and mobilize resources to join initiatives that were already moving forward, and where participation was clearly in the institution’s long-term interest. The second category consisted of somewhat more difficult decisions where an entrenched interest within the institution had to be taken on in order to conserve resources or achieve other goals for the campus as a whole. There were initiatives that would qualify as visionary, but these were few and far between.

Several participating universities have undergone recent changes in organization or have launched standing councils or committees to address IT issues. Personnel changes have sparked some of these changes. Direct CEO-level involvement in these discussions is uncommon. One long-term trend is the increase in the number and proportion of CIOs who come from industry or other non-academic backgrounds, and the corresponding decrease in the number and proportion of CIOs who emerge from the faculty. Interestingly, participation in decision-making processes did not necessarily map on to the composition of the teams that attended the workshop. Several teams featured department heads and others from academic units, while others consisted entirely of central administrators. Overall, the message we got from all four workshops was that leading research universities believe they are doing a good job managing the IT "here and now"; that they are in control regarding the most important issues; and that a cataclysmic meltdown is not a real possibility.

The Learning Environment

Although the influence of the net generation of students was raised in early discussions, there was surprisingly little discussion of the use of IT in the instructional environment. To be sure, most participants recognized the way that technologies such as instant messaging, wireless access, and search engines such as Google were changing both the social interactions and intellectual development of students. Yet there was little discussion of how to harness these new capabilities in the learning environment.

The faculty, by and large, is not as tech savvy as students, and is not aware of the tech-infused culture in which students live and learn. In contrast to the research mission, where the faculty is pushing the boundaries and administrators are forced to respond, in these institutions at least, few faculty members seem involved in cutting-edge use of technology in the instructional domain.

However, this is an arena in which for-profit competition is appearing, where overseas competition might be expected to appear, and where U.S. universities may be in danger of being "Napsterized." The fact that students use one mode of interaction in dealing with faculty because they have to and use another mode when dealing with each other might partially reflect a longstanding intergenerational dynamic. It might also imply that traditional educational institutions are not reaching them, and they are "ripe for the picking" by some new educational institution or instructional mode.

Some participants were confident about the prospects for the optimal uses of technology emerging naturally, while others believed that institutional leaders need to be more proactive in guiding and facilitating. We are left with the questions of how leadership can recognize and leverage strategic opportunities, and how universities can collaborate and learn from one another.

The Library as the Poster Child of the IT Revolution

To make these discussions less abstract, the impact of information technology on university planning for libraries was introduced in several workshops. In a sense the library has become the poster child for the impact of IT on higher education. Beyond the use of digital technology for organizing, cataloguing, and distributing library holdings, the increasing availability of digitally-created materials and the massive digitization of existing holdings (e.g, the Google project to digitize and put online in searchable format the entire holdings of major research libraries) is driving massive change in the library strategies of universities. While most of the universities in our workshops were continuing to build libraries, many were no longer planning them as repositories (since books were increasingly placed in off-campus retrievable high-density storage facilities) but rather as a knowledge commons where users accessed digital knowledge on remote servers. When pressed, it turned out that the most common characteristic of these new libraries was a coffee shop. They were being designed as a community center where students came to study and learn together, but where books were largely absent. The library was becoming a people place, providing the tools to support learning and scholarship and the environment for social interaction.

What is the university library in the digital age? Is it built around stacks or Starbucks? Is it a repository of knowledge or a "student union" for learning? In fact, perhaps this discussion was not really about libraries at all, but rather the types of physical spaces universities require for learning communities. Just as today every library has a Starbucks, perhaps with massive digitization and distribution of library holdings, soon every Starbucks will have a library–indeed, access to the holdings of the world's libraries through wireless connectivity.

In a sense, the library may be the most important observation post for studying how students really learn. If the core competency of the university is the capacity to build collaborative spaces, both real and intellectual, then the changing nature of the library may be a paradigm for the changing nature of the university itself.

Yet the participants in our workshops also raised the very serious issue concerning the preservation of digital knowledge, now increasing at a rate an order of magnitude larger than written materials. Without a more concerted effort for the standardization of curation, archiving, and preservation of digital materials, we may be creating a hole in our intellectual history. Traditionally this has been a major role of the research university through its libraries. There was a general agreement that research universities need to collaborate more on their responsibilities for the stewardship of knowledge in the digital age.

Competition vs. Cooperation vs. Collaboration

Another workshop theme was the degree to which information technology was changing the balance between university competition and collaboration. To be sure, the competitive spirit was alive and well in those workshops involving IT leaders (e.g., MIT, Carnegie Mellon, and Cornell) as well as those with both public and private universities (e.g., the University of California and USC). Yet, just as in the earlier workshops held with presidents and provosts, there was recognition that few, if any, institutions had the capacity to go it alone in technology development and implementation, particularly in the face of monopoly pressures from the commercial section.

This growing need to build alliances was particularly apparent in the middleware and networking area. A new set of open educational resources (open- source tools, open content, and open standards) is being created by consortia such as Open Knowledge Initiative, Sakai, and the Open CourseWare project and being made available to educators everywhere. Networking initiatives led by higher education, grid computing, and other elements of cyberinfrastructure are gaining momentum through alliances such as Internet2 and the National Lamba Rail.

Just as in the IT industry itself, there are emerging trends where universities are cooperating in areas such as cyberinfrastructure and instructional computing that allow them to compete more effectively for faculty, students, and resources. The CIOs in our workshops suggested that the growing consensus on nature IT infrastructure of research universities over the next several years–based on open-source standards and outsourcing stable infrastructure–would demand such cooperative efforts.

Leadership

How does one lead an institution through when key technologies are undergoing such order of magnitude changes? To some participants, the key was empowering the next generation of the faculty. "Our young faculty members generate the best ideas, but traditional academic structures may prevent those ideas from coming to the fore. Therefore, visionary university leadership requires the creation of ad hoc structures that empower young faculty to generate ideas, and focusing presidential attention and resources on the best ones. As long as we can attract the best young faculty, we will be able to stay on the leading edge and innovate."

While this sounded like an appropriate strategy, and the participating schools could clearly point to a number of important initiatives that have emerged in this way, we were not so convinced. Is there really is such a strong flow of innovative ideas in the IT sphere, even from the top young faculty? And if there is such a strong flow, how do leaders then decide which "horses to back" from among the many worthy candidates?

Other participants conveyed a much more skeptical discussion of leadership and governance, at least as it relates to IT. The leadership ideal expressed by one participant was "make a transformative decision, execute, and repeat." However, several participants expressed the view that the changing environment has made it difficult if not impossible for individual leaders to reach this ideal with any consistency. For example, it is more difficult than it used to be to generate a significant impact with a relatively small bet. With the current threshold at $10-$20 million, risk aversion may lead to technology investments being made in dysfunctional ways.

Also, in contrast with the faith that some participants expressed in the ideas of individual faculty as a transformative force, others were more inclined to see the faculty as a group or vested interest standing in the path of needed innovation. In this formulation, even new ad hoc structures could not overcome the dead weight of traditional structures that are not working.

Some even suggested that neither university leaders nor even individual institutions could lead through such an era of rapid and profound change. Rather alliances must be created to provide the leadership, or the monopoly-dominated marketplace itself will lead, perhaps in directions antithetical to the nature of the research university. It could well be that it is the leadership structure of the university itself that has become obsolete, and this is the area in most need of change. Here, one participant reminded us, a true revolution replaces all of the leadership of a society.

General Strategies

Here we found a very significant contrast between two approaches to IT management and development: the optimists, who viewed the chaos of the rapidly evolving IT environment as not only inevitable but tolerable–just let it happen, we can adapt, *hakuna matata* –and the pessimists, who believed that the university needed to control and guide the IT revolution. The former group usually consisted of those institutions that had been leaders in IT development and implementation. They were confident while the revolution would continue, their institutions would remain in a leadership role. (One colleague mentioned the old proverb that one needs not outrun a tiger, but only outrun your companion…)

There was, however, general agreement about the unpredictable and occasionally disruptive nature of this technology. Some felt that the biggest threat was the frustration over constant technological change. Others suggest that folks just "get over it", since continuous change is the key characteristic of a knowledge-driven society. The chaos of IT evolution could be an asset if it stimulated more experiment. Since the marketplace might be a more effective and efficient way to allocate resources and determine priorities, some suggested that universities should strive for an ecology of experimentation and alliances.

An Assessment of the Executive Leadership Core Workshops

In looking back over the year of workshops with the executive leadership cores of 18 leading research universities, the IT Forum has several interesting observations. First, it seems clear that while most university presidents are aware of the challenges posed by rapidly evolving digital technology (their world is indeed "flat"), they do not include it high on their lists of priorities for personal attention. Presidents are looking at IT only as a threat, not an opportunity, and they do not believe this is where the wheels are likely to come off the train, as they are in other more critical areas such as state support, private fund-raising, faculty recruiting, demographic changes in the student population, or federal higher education policy where they prefer to focus attention. Besides, if IT is really an area characterized by chaos, there is little that can be controlled anyway.

This *hakuna matata* attitude is the second issue. To be sure, most of the universities involved in our workshop had long histories of adapting readily to change and sustaining leadership in areas such as technology. The richest universities may well be able to ignore these technology trends, pull up the lifeboats, and feel secure with business as usual. Yet the complacency that accompanies past success can be dangerous, as Lou Gertsner pointed out to the AAU presidents from IBM's history.

The third observation is just how difficult it was to steer these discussions in a more strategic direction, attempting to look over the horizon at the challenges and opportunities that could arise as this technology continued its inevitable progression, a 100 or 1,000 fold over the next decade. While participants would nod their heads, they soon regressed into a "we're positioned well for whatever comes, so lets get back to taking about the details of today's issues". The discussions kept coming back to concern "this is what bothers us now" rather than "where be might be ten years from now".

There was remarkably little conversation about the major changes occurring in scholarship and learning, driven in part by technology. Although there was recognition about the new IT-based communities that were evolving for faculty (e.g., cyberinfrastructure-based, global research communities) and students (e.g., social learning communities based on instant messaging), there was little discussion about how the university could take advantage of this in their educational and research missions.

There was also little evidence that these leaders understood just how rapidly this technology is driving major structural changes in other sectors such as business and government. Today an industry's CIO's life is challenged to reduce IT costs for given productivity by factors of 10 every few years. While university leaders were aware of the productivity gains enabled by a strategic use of technology in industry, they found it difficult to imagine the structural changes in the university capable of delivering such improvement.

To some degree, this unwillingness to think more deeply about the strategic implications of a technology evolving at a Moore's Law pace is evidence again of the complacency characterizing leading research universities. Their perch atop the higher education food chain and their relative wealth leads them to continue doing things the same old way. The real challenge is to pry the leadership away from near-term decisions to focus instead on long-term strategies, on "what" you do rather than "how" you do it.

The Future of Discovery, Learning, and Innovation

In October of 2012, the National Science Foundation sponsored a workshop at the University of Michigan to assess the impact of rapidly evolving information and communications technology (i.e., cyberinfrastructure) on the activities of discovery, learning, and innovation. This workshop convened an unusually diverse group of thought leaders from multiple disciplines and venues to consider the changing nature of learning and discovery in broad terms, spanning learning at all levels and discovery for all forms including research, development, innovation, invention, design, and creativity. The objectives of the workshop included: i) suggesting key research questions, likely game-changers, and possible paradigm shifts, ii) framing an interdisciplinary research agenda for the next decade, and iii) identifying possible research programs, experiments, and organizational structures that would best meet the needs of the nation in this rapidly changing environment. In simpler terms, the goals of the workshop were to set an agenda for the exploration how to transform the what, the how, and who participates in discovery and learning; to personalize and broaden participation in discovery and learning; and to accelerate discovery and the transfer from discovery to innovative use.

More specifically, the topics considered by the workshop considered the impact of powerful technologies such as always-on, ubiquitous connectivity (anywhere, anytime, everyone); social networking, crowd sourcing, collaborative learning and discovery, functionally complete cyberinfrastructures, emerging learning paradigms such as massively open online courses (MOOCs), cognitive tutors, gaming, immersive experiences; big data, data-intensive discovery, learning analytics, intelligent software agents: and possible surprises such as cognitive implants. Of particular concern were the impact of emerging technologies on both learning institutions and learning paradigms? Similarly consideration was given to the way in technology was transforming research paradigms (e.g., data centers (clouds), big data (analytics), crowd sourcing, and open knowledge resources) In particular, the roundtable of participants was challenged to suggest a framework for the conduct of research concerning the impact of possible emerging technologies on the conduct of scientific research, technological innovation, and STEM education. Of particular interest was the identification of possible advances in technology that could radically transform the existing paradigms for these activities.

Organization of the Workshop

The workshop was organized as a series of moderated roundtable discussions captured by both experienced rapporteurs and video in a special studio that allowed multiple HD cameras and directional sound systems capable of recording the dialog among various participants for later distribution over the Internet. The workshop was organized into four specific sessions:

The Duderstadt Center at the University of Michigan

Changing Needs for Discovery and Learning: Here the focus was on the rapidly changing needs of society for workforce learning and skills, new knowledge, research, innovation, and creativity in a world increasingly integrated and transformed by digital technology. The differing priorities for learning and discovery were examined at the level of individuals, organizations, nations, and the world. The impact of demographic change (from baby boomers to Millennials to Gen Z), workplace needs (adaptive, ubiquitous, and lifelong learning opportunities), and learning structures (explicit, tacit, and intuitive knowledge) were considered. Different forms of discovery were also considered, e.g., transformational to translational to entrepreneurial R&D, as well as differing needs at the organization level (business, industry, government, OECD, emerging economics, and the developing world). The key question facing the group was: "Scientific and technology-enabled workspaces will soon be enormously different. How can we prepare our citizens–researchers, workers, and leaders–for this future?"

The Future Evolution of Digital Technology: Here the topics included the emergence of always-on, ubiquitous connectivity (anywhere, anytime, everyone); social networking, and collaborative learning and discovery, collaboratories; four-quadrant paradigms (i.e., same place/same time; same place/different times; different places as the same time; and different places at different times) and functionally complete cyberinfrastructures; emerging learning paradigms such as intelligent tutors, gaming, immersive experiences; big data, data-intensive discovery, visual analytics, intelligent software agents: and possible surprises such as cognitive implants. The key question: "We will have amazing tools. How can we use them in the service of learning and discovery?"

Possibilities, Game-Changers, and Paradigm Shifts: This session addressed questions such as: How might these emerging technologies transform learning institutions (schools, colleges, workplace training, lifelong learning, open learning) and paradigms (from learning to know, to learning to do, to learning to become)? How are research paradigms likely to change (Pasteur's Quadrant, citizen scientists, crowd sourcing, open knowledge)? Could these drive major social transformations such the Renaissance and Enlightenment that appeared during earlier eras of major changes in discovery and learning. The key question: "The environments for discovery and learning face transformative change. What must learning institutions do to enable this change?"

Paths to the Future of Discovery and Learning: The final session focused on specific findings and recommendations for consideration of federal agencies, educational institutions, industry, foundations, and other organizations and communities concerned with scientific discovery, innovation, and learning. In particular, the roundtable was be challenged to suggest a framework for the conduct of research concerning

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the impact of possible emerging technologies on the conduct of scientific research, technological innovation, and STEM education. Here the panel included expertise in learning sciences and cognitive science, selected in particular to help uncover how the new possibilities can build on the past half-century of research on how people learn. For example, how does our understanding of human memory and information processing inform the design of new interfaces to extend human capability? How do we design learning and discovery environments that emphasize "21st Century Skills" while ensuring that learners at all levels achieve necessary mastery of core topics? Of particular importance here was the identification of possible advances in technology that could radically transform the existing paradigms for discovery and learning activities (e.g., "Watson in your pocket"). Here the roundtable was asked to suggest new research programs, experiments, and organizational structures that could augment or replace existing discovery, innovation, and learning paradigms. In addition, consideration was given to the social and organizational challenges in exploiting the power of these technologies.

Session One: The Changing Need for Discovery and Learning

Demographic Challenges

The first set of discussions concerned the radically different demographics charactering developed and developing economies. For example, the populations of most developed nations in North America, Europe, and Asia are aging rapidly where over the next decade the percentage of the population over 60 will grow to over 30% to 40%. Half of the world's population today lives in countries where fertility rates are no longer sufficient to replace their current populations. In sharp contrast, developing nations in Asia, Africa, and Latin America are characterized by young and growing populations in which the average age is less than 20. The number of students enrolled in higher education by 2030 is forecast to rise from 100 million in 2000 to 400 million in 2030 – an increase of 314%. Here the demand for education is staggering since in a knowledge economy, it is clear to all that this is the key to one's future security. Unless developed nations step forward and help address this crisis, billions of people in coming generations will be denied the education so necessary to compete in, and survive in, the knowledge economy.

Today we see a serious imbalance between educational need and educational capacity–in a sense, many of our universities are in the wrong place, where populations are aging and perhaps even declining rather than young and growing. This has already triggered some market response, with the entry of for-profit providers of higher education (e.g., Laureate, Apollo) into providing higher education services on a global basis through acquisitions of existing institutions or distance learning technologies. But more significantly, meeting this demand will require new forms of technology-enabled learning such as Massively Open Online Courses (MOOCs) and the Open Learning Initiative. Yet, even if market forces and technology-enabled learning paradigms are successful in addressing the urgent educational needs of the developing world, there are also concerns about whether there will be enough jobs to respond to a growing population of college graduates in many of these regions.

The Educational Needs of 21st-Century Citizens

It is estimated over 80 percent of the new jobs created by our knowledge-driven economy require education at the college level, and for many careers, a baccalaureate degree will not be enough to enable graduates to keep pace with the knowledge and skill-level required for their careers. The knowledge base in many fields is growing exponentially. In some fields such as engineering and medicine the knowledge taught to students becomes obsolete even before they graduate! Hence a college education will serve only as a stepping-stone to a process of lifelong education. The ability to continue to learn and to adapt to—indeed, to manage—change and uncertainty are among the most valuable skills of all to be acquired in college.

Both young, digital-media savvy students and adult learners will likely demand a major shift in educational methods, away from passive classroom courses packaged into well-defined degree programs, and toward interactive, collaborative learning experiences,

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provided when and where the student needs the knowledge and skills. There will be a shift from "just in case" learning, in which formal education is provided through specific degree programs early in one's life in the hope that the skills learned will be useful later, to "just in time" lifelong learning, in which both informal and formal learning will be expected to occur throughout one's life, when it is relevant and needed to "just for you" learning, highly customized to the needs and styles of the learner. This suggests that most of one's learning will occur after the more formal K-16 experience, either in the workplace or other learning environments. The increased blurring of the various stages of learning throughout one's lifetime–K-12, undergraduate, graduate, professional, job training, career shifting, lifelong enrichment–will require a far greater coordination and perhaps even a merger of various elements of our knowledge infrastructure.

The Changing Nature of Learning

Yet while learning and teaching in higher education is changing, both those driving change and those who need to change (professors/instructors) do not always know how. Learning is happening outside formal structures like the classroom, through hands-on engagement, internships and apprenticeships. It has become life-long and life-wide. The physical spaces where learning happens on campus can be more or less facilitative of learning, and universities have the power to create such spaces, if they recognize the need and value the craft aspects of learning. Part of the challenge here is to understand better how the learning experiments around the edges of learning institutions is challenging and changing traditional forms of pedagogy.

Should educational institutions challenge these characteristics of today's youth, such as multiprocessing homework, texting, gaming and music or capability for rapid context switching, increasingly both created by and necessary to master emerging technologies? Or should we allow our students to adapt naturally to the power of communication using mobile devices and social networks that enable learning through online interactions, particularly among peers, rather than the more structured classroom curriculum charactering today's institutions. Perhaps we have not thought sufficiently about connecting the dots of all the learning options that students have these days!

Lifelong Learning

In a global economy increasing driving by rapidly evolving knowledge and technology, a nation's workforce will require ever more sophisticated and sustained education and training to sustain its competitiveness. Today's graduates will change careers many times during their lives, requiring additional education at each stage. Furthermore, with the ever-expanding knowledge base of many fields, along with the longer life span and working careers of our aging population, the need for intellectual retooling will become even more significant. Even those without college degrees will soon find that their continued employability requires advanced education. Hence opportunities for lifelong education will become a necessity for a knowledge-driven world.

Unfortunately, with the exception of a few of the professional schools such as medicine, business, and law, there is ample evidence that most faculty members have not been very interested in developing the paradigms necessary for adult education, e.g., the short courses and training programs that will help with new skills. Trying to find a way for the university to incorporate more of the educational apparatus to equip people for lifelong issue is a very big issue, and we have not dealt with it well. Fortunately recently emerging technology-based learning paradigms such as MOOCs and open learning seem particularly well suited to providing lifelong learning opportunities for adult students, since their strong emphasis on both synchronous and asynchronous online education and social networks to build huge learning communities address particularly well the constraints faced by working adults.

It was noted that the flipside of lifelong learning is that students do not have to wait until later in life to learn about the workplace. In fact, most want to get out of universities faster, since these are expensive, and there are plenty of other learning opportunities beyond the campus. Students are already well into their lives when they arrive on campus, and they are taking control of their educational experiences. They are using technology to access learning opportunities beyond the formal curriculum, using digital knowledge resources such as Google, Wikipedia, and digital libraries and building learning communities with other students. We have to understand that the university is no longer the warden for student learning, if it ever was. Instead we have to take advantage of the "life-wide" nature of student learning, just as we have to prepare them for livelong learning activities.

The Changing Nature of Research and Scholarship

The evolution of powerful cyberinfrastructure is driving significant change in the paradigms for discovery and research. With the exploding capacity of sensor technology and data centers, data mining (analytics) as been added to the traditional scientific processes of observation, hypothesis, and experiment, becoming more data correlation driven than hypothesis driven. Both fundamental research and product development are increasingly dependent on simulation from first principles requiring massive supercomputers rather than experimental measurement and testing. If one subscribes to the view that there is a paradigm shift from hypothesis driven to data driven discovery and simulation, then it is clear that the entire conduct and culture of scientific and engineering discovery and innovation is changing as a result of access to data, technology and social networks. We are going to need new models for sharing data, software, and computational resources.

Yet another concern is the degree to which many companies are embracing philosophies of outsourcing the risks of research, encouraging scientists and engineers to leave the "mother ship" of the company to do a start up such as developing a cloud-based software platform, thereby assuming all the risk, but eventually hoping to be reacquired by the old company through de novo financing. Another pragmatic approach is to offshore corporate research to less expensive research centers in countries like India or China.

As a result, little of today's corporate R&D was basic in nature but rather consisted of extrapolation of existing knowledge through applied research and development. In fact it was suggest that much of the technology of American industry was largely based on scientific research conducted in the 1950s and 1960s in the Cold War era. There was significant concern expressed about the disappearance of major industrial research laboratories such as Bell Laboratories or the Ford Scientific Laboratory, capable of significant translational research connecting basic research with applied research and development to create new products and processes to be transferred into the marketplace to service society. This suggests that we need a new relationship among universities (where basic research and advanced education occurs), national laboratories (where very large-scale R&D projects are launched, and industry (where both unique facilities and data sets exist).

Access to the Tools and Data Necessary for Cutting-Edge Research

Today there are major questions with respect to who has access to and control of scientific data. Much data exists in the private sector and is unavailable to researchers in higher education–a break from the past, even in the Cold War years where there much research was constrained by security classification. We are beginning to see a phenomenon of research going where data is and hence migrating to corporate settings. This is creating a deluge of strange results. Experiments and findings are hard to reproduce because scientists cannot get at underlying data. Conclusions that become folklore rather than rigorously reproduced experiments spread quickly through networks.

There were also concerns expressed by representatives from industry that graduate students were not being adequately trained to meet their needs, in part because of the increasing sophistication of technology required for the analysis and development of industrial processes that was simply unavailable on the campuses. Conversely, students coming out of higher education have values that industry does not always share. The open and collaborative nature of recent graduates butts up against intellectual property and privacy rules as well as existing corporate culture.

It was acknowledged that the responsibility for adequate training in such areas required more intimate partnerships between universities and industry. Yet industry participants also acknowledged their practice of luring talented undergraduates in the areas of software development to leave their studies prior to their degrees. Several industry participants admitted they were eating their own seed corn in pursuit of near term profits.

Craftsmanship

Several participants noted a structural hole that had appeared in today's learning institutions that could impact innovation. In earlier times, when universities were brilliant at doing ideation, and industry was brilliant at de-risking everything and grinding away, there were places like Bell Labs, Xerox PARC, SRI, etc. that had as many craftspeople as scientists. They could build anything, and they built it well. Those people never got recognition. But in labs themselves, shoulder to shoulder, they had as much reputation as any of the PhD's within the organization. This group built the stuff that enabled a serious conversation with engineering and manufacturing companies about product development.

Yet today we have a situation where there are few institutional mechanisms to do the applied research to take ideas into prototypes because of the rapid payback required by venture capital. Furthermore applied research activities based on craft as much as science, and universities are not that good at keeping people good at craft around for time required for these developments. Other players such as the national laboratories still emphasis craft in their major activities, but their cultures and infrastructure are directed at major project work rather than product-oriented R&D needed by industry.

Several European nations such as Germany and Switzerland are much better at creating and valuing craftsmanship. They understand the importance of craft and have developed both the educational structures (e.g., Fachhohenschulen for learning in the applied sciences and the Fraunhofer Institutes for applied technology research) and the reward system to encourage and sustain it. Fortunately today in the United States there are early signs such as the "maker" movement that suggest that young people are becoming very interested once again in making things. A culture of wanting to build stuff is beginning to appear again, but higher education is not geared up for this yet.

Industry Views of the University

One of the great challenges facing the American research university is the lack of understanding of their broad mission as the nation's key asset for the conduct of basic research (providing over 50% of the national effort), producing the next generation of scientists and scholars, and knowledge professionals (engineering, medicine, law, etc.), providing state-of-the-art health (university medical centers), and attracting global talent (both students and faculty). Hence it was surprising– indeed, alarming– that several of the participants from high-tech industry stressed that the primary purpose of these institutions should be to provide the low-cost mass education and training specific to meeting the immediate needs of industry. In fact, some participants even discounted the value of campus-based research, arguing that in today's economy, it is more efficient to outsource R&D to small spinoff companies or cheaper offshore providers. Another surprise from the discussions was the belief that university research and education were becoming less and less relevant to the information technology industry. There seemed to be a confidence that IT companies, particularly those in software development, could get all the R&D help they need by either outsourcing it to small spinoff companies, offshore it to low cost economies), or simply pluck an outstanding student or faculty member out of a university.

This view seems to have colored the current relationship between universities and the computer industry, which today lags many other industries such as pharmaceuticals in the support of campus-based research. This is ironic, since the basic research conducted on the campuses laid the fundamental foundation for computing, e.g., mathematical logic, solid state physics, systems analysis, while the technology needs of faculty members and the innovation from students drove much of the innovation in the industry (e.g., Univac, CDC, DEC, Microsoft, Apple, Google, Facebook, etc.). Furthermore, many of the paradigms characterizing today's technology actually began on the campuses (e.g., digital computing, time sharing, the Internet, search algorithms, data mining, cognitive tutors). Hence the absence of more robust relationships between today's industry and higher education could well become its Achilles heel because of the growing need for basic research in areas such as artificial intelligence, DNA storage, and quantum computing necessary to advance the technology.

Session Two: The Future Evolution of Digital Technology

The End of Moore's Law?

Although most characteristics of cyberinfrastructure, e.g., processing power, data storage, network bandwidth continue to increasing at an exponential pace described by Moore's law, various components of the technology do eventually encounter limits and saturation that require major technology shifts. For example, VLSI processors and memories are approaching the limits of miniaturization and hence processing speed. In the near term devices are exploiting multiprocessor architectures, with dozens of processors on a single chip (and millions of processors in supercomputers). But other constraints such as power requirements will soon require new technologies such as DNA storage and quantum computing.

Similar evolution continues to occur in how information is processed. For example, companies such as Google are built around data centers, analyzing and extracting information and knowledge from large data centers (or clouds). Here scale truly matters, with increases of factors of ten in storage and processing speed regularly required and achieved to meet market requirements. Similarly, data concepts have shifted to larger, more abstract structures such as entitles, concepts, and knowledge, that require enormous increases in data storage and processing speed. They also require more sophisticated software for data processing to enable rapid searches for abstract concepts through petabytes of data.

The Human Interface

One of the most rapidly changing characteristics of this technology involves the human interface. Although we look back at the transition from text to image to video to 3D immersive displays, there are other characteristics such as mobility, size, and context that also change rapidly. For example, the development of software agents that rely on natural interactions such as speech and context awareness are already transforming both mobile phones (e.g., Apple's Siri) and interfaces with the physical world (e.g., imbedding computing into eyeglasses to assist in context analysis).

Similarly, there is great interest in the evolution of the Internet into a network of objects such as ubiquitous sensors, the rise of contextual data, and the ability to do predictive models of individual behavior. The need for accessibility raises the issue of digital inclusion in the broadest sense. How does one design technology to assist physically challenged individuals, aging populations, those with limited literacy skills, indeed, providing a global population of 10 billion with robust digital access.

The Evolution of the IT Industry

The history of the computing and communications industry has followed Schumpeter's process of creative destruction. Each major technology turn has been accompanied by the emergence of new companies that frequently destroy the old. While new companies such as Facebook, Google, and Amazon have exploited new paradigms such as social network, big data, clouds, and data mining to rapidly rise to global prominence, they may also be following the evolutionary pattern of earlier market leaders such as Control Data Corporation, Digital Equipment Corporation, and the Bell System.

One interesting scenario is long-term status of the United States IT ecosystem. As an example of how this is evolving consider mobile devices. Remember here that most of mobile phone users on the planet are not from Europe and not from North America but rather from Asia and increasingly Latin America. That will forever more be true. That ratio only continues to expand. For most of these people the mobile phone is their definition of computing. It is not just their primary computer device but usually their only technology. Yet a second example is the continuing outsourcing of the U.S. silicon ecosystem, the whole mix of captive silicon foundries versus open foundries and open intellectual property. This has major implication for not only national competitiveness but also national security. Currently this migration of hardware development is counter balanced by innovation in the software space. But even here we have already begun to lose our status as a major player.

The Next Big Paradigm Shift

So, what are the early warning systems for major paradigm shifts? What does one look for? Do you look at the research labs on college campuses? Or do you look at Harvard dormitories for what students are doing before they drop out? Do you try to spot the next Bill Gates, Mark Zuckerberg, or Larry Page? Do you have any tracking systems?

Industry participants responded with "No, we don't look at the campuses until things break out of them. We try to spot activities characterized by hyper exponential growth, things that are growing every year by a factor of two or more. If we spot interesting students or faculty in universities, we try to extricate them as soon as possible. The success model is what escapes not what stays inside."

Again from industry's viewpoint, the elephant in the in room is knowledge creation, not knowledge dissemination. Of course, this is the unique role of the research university, albeit in addition to its other missions of knowledge dissemination (e.g., teaching, service). The stovepipe structure in academia (and NSF itself) is stifling. We have commoditized knowledge generation.

We need to be more focused on knowledge creation, integration, synthesis, and dissemination. This involves working to broaden access through libraries, search tools, and push models in education. This is the big opportunity that research universities have to embrace. It is about DIKW: data, information, knowledge, and wisdom. One needs to use cyberinfrastructure together with creation tools, and universities are not stepping up to that.

Resilience

We need to think more about robustness and resilience of cyberinstructure and our knowledge systems. In rapidly changing environment, the capability of responding and being flexible and making smart choices without planning and thinking in advance become extremely important. The academy does not seem to be preparing students for understanding what "big data" really means. What happens when you start changing orders of magnitude, or when noise becomes signal as you amplify it? In the next few years we will be experiencing exa-data. Yet we have very few data scientists. The universities are not churning them out the people who actually know how to do the analysis. There is a sense that we now have fundamentally new tools that will give payoff, if you really do understand data analytics, the mathematical models, but more so if we also understand math, physics, chemistry, and other sciences and know how to bring them together? After all, the correlations identified through data mining to not necessarily lead to causal explanations.

The mental model of cloud-based knowledge and learning is intrinsically difficult. The fundamental challenge is that industry is actively building new stuff all the time. While this is a benefit for doing something innovative, it is not necessarily a good thing if you have a thousand companies innovating in an incompatible manner. Deleting in this case is non-deleting in that case. It is an ecology problem. We live not in the single system we are building but rather in an ecosystem with multiple providers of multiple things. As participant asked: "Do digital natives have any better mental models of new knowledge paradigms such as clouds? I don't think they have deep computational models or insights. I don't know. I really don't."

Session Three: Possibilities, Game-Changers, and Paradigm Shifts

The workshop participants were encouraged that in their discussion of possibilities, game-changers, and paradigm shifts in discovery, learning, and innovation, they try to strike a balance between identifying possibilities vs. arguing whether they will occur or not. They were invited to suggest important missing topics that need to get on table. Techies tend to talk about change-change-change. But there is also a need to talk about things that will not change. If there are things that are invariant, protected, and nurtured, we should identify them.

Cyberinfrastructure now allows tools, data, experiments, and other assets to support online knowledge communities, making these functionally complete in any of the four quadrants, that is, with all the resources necessary to handle knowledge flow. Using the scaffolding of cyberinfrastructure, one can dramatically reduce constraints of distance and time. This creates a major disruption in how knowledge work is done, expanding significantly the degrees of freedom.

New Paradigms for Learning and Teaching

So what are the opportunities presented by cyberinfrastructure for learning and teaching, for example Massively Open Online Courses (MOOCs) or cognitive tutor systems or Carnegie Mellon's Open Learning Initiative. Are these something new? Or is this really just old wine in new bottles? After all, millions of students have been using online learning for decades (estimated today to involve over one-third of current students). There are lots of highly developed models, including the UK Open University and the Mellon Foundation's asynchronous learning paradigms.

Of course today's MOOCs do have some new wrinkles, aside from the massive markets they are able to build through the Internet and their current practice of free access. Their semi-synchronous structure, in which courses and exams are given at a specific time while progress is kept on track, allows them to leverage both grading and advising from more advanced students through social networks. (Here one might think of MOOCs as a clever combination of UK's Open University and Wikipedia!) Furthermore MOOCs, like the far-more sophisticate Open learning Initiative, are able to use data mining (analytics) to gather a large amount of information about student learning experiences. When combined with cognitive science, this provides a strong source of feedback for course improvement.

More broadly, there are many other emerging and rapidly evolving learning technologies:

E-books, digital libraries, and intelligence clouds of data
Online synchronous and asynchronous lectures (over all four quadrants)
Analytics on student performance and new approaches to learning research
Use of artificial intelligence to create cognitive tutor systems (sans faculty)
Massively multiplayer gaming (e.g., World of Warcraft or MineCraft)
Immersive technologies (e.g., Second Life, Enders Game)

So what do we know about these new paradigms? Certainly there is a great deal of hype (e.g. that they will unleash a tsunami upon higher education). But where is the beef? Where are the careful measurements of learning that rigorously compare new paradigms such as MOOCs with classroom, studio, or tutorial-based learning? What are the advantages of technology-based learning? Cost and efficiency? Access to gigantic markets (with significant revenue potential)? Standardization…or customization? Capacity to gather data on learning and improve pedagogy? Quality of the learning experience?

Of course, it eventually leads back to a consideration of the most valuable form of learning and how it occurs? Through formal curricula? Through engaging teachers? Through learning communities? Particularly at the graduate level, centuries of experience suggest that the medieval concept of a Universitas Magistrorum et Scholarium, a gathering of scholars and masters, may not only be the most valuable form of learning, but also the most difficult to automate in a technology-intensive environment.

Knowledge communities fracture in strange and interesting ways. MOOCs are just one example of many new kinds learning technologies appearing that represent efforts to try to take over part of what the university nominally does but doing it better. These are not just flipping the classroom but flipping the entire model of the university. Of course, many of these efforts are driven by the exploding global needs for higher education mentioned earlier. For example, to meet the needs of its population, India would have to build 1.500 new universities just to handle its current number of secondary school graduates. There is no way that is going to happen. Hence there are gigantic markets that raise issues of scale.

Worries were expressed about the hype given MOOCs by the media. Certainly this paradigm is characterized by a powerful delivery mechanism. But it is just one model. It is much more important to focus on improving learning by integrating emerging technology with research about how people learn. We need to keep an open mind. Exploring these opportunities will be good for the learning business. There is no question that there will be transformative aspects of this. But there are also other models to explore and much richer collaboration opportunities to share. Through knowledge creation, we need to embrace new paradigms as a community.

The arc of conversation about technology-enabled learning was interesting. It started with MOOCs and how that paradigm could deliver education more cheaply to gigantic markets of users. Then it moved to speculation about whether these could not only lower the cost of education but perhaps shift learning to a new learning paradigm that would create a tsunami sweeping over universities. Yet it was also observed that 500 years it was thought that the printing press would destroy the medieval university. We would no longer need teachers since students could just read the books. As Clark Kerr's famous quote suggests, the university today remains one of the most enduring social institutions.

We must remember that there are actually students living on a university campus, completely immersed in an exciting intellectual and social physical environment and sophisticated communities where most of the learning occurs far from the classrooms and instead through groups of students and teachers, interacting in diverse environments including laboratories, studios, and clinical settings. On a university campus we hope to have people–not just students but faculty and staff–engaged in learning activities all of their waking hours, and in the case of faculty at least, throughout their lives. MOOCs are interesting, but they are far from the vibrant, immersive environment of a college education, at least as we understand it today. And, as yet, there is little rigorous evidence of their learning effectiveness. Most of the efforts in learning science have not looked small experiments in traditional institutions. Learning science as a field is not ready yet for looking more broadly at more flexible learning communities.

A great thing about universities is that there are so many interesting things going on. Companies such as Google and Microsoft are always so focused. Universities have a breadth of opportunities because by design, they are optimal at driving curiosity and creating serendipity. This is a very important theme to think about. Where is the real value added for university environment.

The Challenge of Inequity in Learning Opportunities

Here one must keep in mind the following fact characterizing American higher education today: If you are smart and poor (bottom quartile), you have only a 10% chance of earning a college degree. If you are dumb and rich (top quartile), you have a 90% chance. The rapidly changing nature of our world challenges our adherence to the traditional disciplines. This is part of what happens and affects low-income kids. We are teaching kids curriculum in K-12 schools that do not prepare them for the world they are coming from and going to. They are double burdened: both how they have been prepared and where they are going.

One of the findings from large ethnographic studies of the way kids are learning on line speaks to social nature of learning through peer-to-peer interaction. This is incredibly important. In a social world, peer to peer learning, apprenticeship can look a lot of different ways. The way kids find their interest starts off with kids hanging out with each other. What are you doing? What does that look like? That looks interesting. I want to tinker with that. Play with that. I want to mess around with that. I want to go deeper – asking each other how to do it. This is an incredibly efficient form of learning. People finding out how to do things and learning that from each other is efficient as long as we scaffold and construct those spaces. Yet have also learned that in the fear-driven communities, sometimes we do not allow kids to hang out together. We only provide geeking out, collaborative space around STEM education for people to go into specific programs. And universities cannot leverage this. For our youth, we do that in kindergarten, but we lose it for middle school and high school kids. We lose the opportunity to play and innovate. If you separate content from context and you get these didactic approaches that leave out particularly low-income kids. When we start talking about "we need fundamentals, we need core." That's what has been happening to our education system for last decades. We have not been addressing the broader set of learning issues related to how kids behave. Perhaps we need math and physics moms like soccer moms, parents showing kids that it is important? The social incentive to be a geek is not high.

Is the Paradigm for Basic Research Really Changing?

Are research and scholarship paradigms shifting? How? We all hear the buzzwords: clouds, analytics, convergence, etc. Is the way in which research is changing? What about global competition? Is the world of high-energy physics sustainable where you send people off to only one place CERN to do the work, resulting in a list of authors longer than substance of the papers? Are we moving to a wiki world where crowd sourcing of amateurs becomes important? How important is the role of research and scholarship within universities? Do we need tweaking of tax laws so the translational research of Bell Labs begins to reappear as part of the knowledge ecosystem?

Crowd-sourcing, open software, Wikipedia, and social networking enable certain forms of research to fractionalize. But there are deeper fiscal properties. What about the instrumentation (including distributed sensor technology) necessary to generate data? Have we done all the physical things we need so we need not invest in massive experimental facilities like the Large Hadron Collider or missions to the outer planets? Of course, most scientists would contend that industry is really not talking about basic research anymore. Rather they are basing their activities primarily on the applications of things known. Yet if you ask more broadly what society needs from universities, it clearly needs basic research. No one else is doing generating the new knowledge that applied research flows from. Without that you don't get building blocks for innovative applications.

A Caution about Change in Universities

We should remember that while many think of the university in medieval terms, that universities change only one grave at a time, in reality universities change very quickly and in profound ways. It is true that the university today looks very much like it has for decades–indeed, centuries in the case of many ancient European universities. They are still organized into academic and professional disciplines; they still base their educational programs on the traditional undergraduate, graduate, and professional discipline curricula; our universities are still governed, managed, and led as they have been for ages.

But if one looks more closely at the core activities of students and faculty, the changes over the past decade have been profound indeed. The scholarly activities of the faculty have become heavily dependent upon digital technology–rather cyberinfrastructure–whether in the sciences, humanities, arts, or professions. Although faculties still seek face-to-face discussions with colleagues, these have become the booster shot for far more frequent interactions over the Internet. Most faculty members rarely visit the library anymore, preferring to access digital resources through powerful and efficient search engines. Some have even ceased publishing in favor of the increasingly ubiquitous digital preprint or blog route. Student life and learning are also changing rapidly, as students bring onto campus with them the skills of the net generation for applying this rapidly evolving technology to their own interests, forming social groups through social networking technology (Facebook, Twitter), role playing (gaming), accessing web-based services, and inquiry-based learning, despite the insistence of their professors that they jump through the hoops of the traditional classroom paradigm.

In one sense it is amazing that the university has been able to adapt to these extraordinary transformations of its most fundamental activities, learning and scholarship, with its organization and structure largely intact. Here one might be inclined to observe that technological change tends to evolve much more rapidly than social change, suggesting that a social institution such as the university that has lasted a millennium is unlikely to change on the timescales of tech turns, although social institutions such as corporations have learned the hard way that failure to keep pace can lead to extinction. Yet, while social institutions may respond more slowly to technological change, when they do so, it is frequently with quite abrupt and unpredictable consequences, e.g., "punctuated evolution".

It could also be that the revolution in higher education is well underway, at least with the early adopters, and simply not sensed or recognized yet by the body of the institutions within which the changes are occurring. Universities are extraordinarily adaptable organizations, tolerating enormous redundancy and diversity. It could be that the information technology revolution is more of a tsunami that universities can float through rather than a rogue wave that will swamp them.

Admittedly it is also the case that futurists have a habit of overestimating the impact of new technologies in the near term and underestimating them over the longer term. There is a natural tendency to implicitly assume that the present will continue, just at an accelerated pace, and fail to anticipate the disruptive technologies and killer apps that turn predictions topsy-turvy. Yet we also know that far enough into the future, the exponential character of the evolution of Moore's Law technologies such as info-, bio-, and nano-technology makes almost any scenario possible.

Clearly we have entered a period of significant change in higher education as our universities attempt to respond to the challenges, opportunities, and responsibilities before them. This time of great change, of shifting paradigms, provides the context in which we must consider the changing nature of the university.

Impact: Whence and Whither the Revolution

The report characterizing the first phase of this study of the impact of information technology on the university was entitled *Preparing for the Revolution*. But what revolution? The university today looks very much like it has for decades, still organized into academic and professional disciplines; still basing its educational programs on the traditional undergraduate, graduate, and professional discipline curricula; still financed, managed, and led as it has been for many years.

Yet if one looks more closely at the core activities of students and faculty, the changes over the past decade have been profound indeed. The scholarly activities of the faculty have become heavily dependent upon digital technology–rather cyberinfrastructure–whether in the sciences, humanities, arts, or professions. Although faculties still seek face-to-face discussions with colleagues, these have become the booster shot for far more frequent interactions over Internet. Most faculty members rarely visit the library anymore, preferring to access far more powerful, accessible, and efficient digital resources. Many have ceased publishing in favor of the increasingly ubiquitous preprint route. Even grantsmanship has been digitized with the automation of proposal submission and review and grant management and reporting by funding agencies. And, as we have noted earlier, both student life and learning is also changing rapidly, as students bring onto campus with them the skills of the net generation for applying this rapidly evolving technology to their own interests, forming social groups, role playing (gaming), accessing services, and learning–despite the insistence of their professors that they jump through the hoops of the traditional classroom paradigm.

In one sense it is amazing that the university has been able to adapt to these extraordinary transformations of its most fundamental activities, learning and scholarship, with its organization and structure largely intact. Here one might be inclined to observe that technological change tends to evolve much more rapidly than social change, suggesting that a social institution such as the university that has lasted a millennium is unlikely to change on the timescales of tech turns–although social institutions such as corporations have learned the hard way that failure to keep pace can lead to extinction. Yet, while social institutions may respond more slowly to technological change, when they do so, it is frequently with quite abrupt and unpredictable consequences, e.g., "punctuated equilibrium". It could also be that the revolution in higher education is well underway, at least with the early adopters, and simply not sensed or recognized yet by the body of the institutions within which the changes are occurring.

Universities are extraordinarily adaptable organizations, tolerating enormous redundancy and diversity. It could be that information technology revolution is more a tsunami that universities can float through rather a tidal wave that will swamp them. One of our participants suggested that perhaps what we should view the transformation of the university as an evolutionary rather than a revolutionary process. Evolutionary change usually occurs first at the edge of an organization (an ecology) rather than in the center where it is likely to be extinguished. In this sense the cyberinfrastructure now transforming scholarship or the communications technology enabling new forms of student learning have not yet propagated into the core of the university. Of course, from this perspective, recent efforts such as the Google project take on far more significance, since the morphing of the university library from stacks to Starbucks strikes at the intellectual soul of the university.

It is certainly the case that futurists have a habit of overestimating the impact of new technologies in the near term and underestimating them over the longer term. There is a natural tendency to implicitly assume that the present will continue, just at an accelerated pace, and fail to anticipate the disruptive technologies and kill apps that turn predictions topsy-turvy. Yet we also know that far enough into the future, the exponential character of the evolution of Moore's Law technologies such as info-, bio-, and nano- technology makes almost any scenario possible.

While perhaps not enabling the level of strategic discussions that we had hoped, the IT Forum certainly reinforced the good-news, bad-news character of digital technology. The good news is that it works, and eventually it is just as disruptive as predicted. The bad news is the same: this stuff works, and it is just as disruptive as predicted.

In this spirit, then, perhaps we should end with a discussion that occurred with the AAU provost's workshop in 2004. While university presidents are reluctant to let speculation about the survival of the university on the table, not so with provosts, who were quite comfortable talking about very fundamental issues such as the values, roles, mission, and even the survival of the university, at least as we know it today. During this discussion it was pointed out during the 19th century, in a single generation following the Civil War, essentially everything that could change about higher education in America did in fact change: small colleges, based on the English boarding school model of educating only the elite, were joined by the public universities, with the mission of educating the working class. Federal initiatives such as the Land Grant Acts added research and service to the mission of the universities. The academy became empowered with new perquisites such as academic freedom, tenure, and faculty governance. Universities increased 10-fold and then 100-fold in enrollments. The university at the turn of century bore little resemblance to the colonial colleges of a generation earlier.

The consensus of our discussions with the provost suggested that we are well along in a similar period of dramatic change in higher education. In fact, some of our colleagues were even willing to put on the table the most disturbing question of all: Will the university, at least as we know it today, even exist a generation from now? Disturbing, perhaps. But certainly a question deserving of very careful consideration, at least by those responsible for leading and governing our institutions, suggesting that perhaps such studies should shift from "the impact of technology on the future of the research university" to "the impact of technology on scholarship and learning, wherever they may be conducted"!

Certainly the monastic character of the ivory tower is certainly lost forever. Although there are many important features of the campus environment that suggest that most universities will continue to exist as a place, at least for the near term, as digital technology makes it increasingly possible to emulate human interaction in all the sense with arbitrarily high fidelity, perhaps we should not bind teaching and scholarship too tightly to buildings and grounds. Certainly, both learning and scholarship will continue to depend heavily upon the existence of communities, since they are, after all, high social enterprises. Yet as these communities are increasingly global in extent, detached from the constraints of space and time, we should not assume that the scholarly communities of our times would necessarily dictate the future of our universities. Even in the near term, we should again recall Christensen's innovators's dilemma , as these disruptive technologies, which initially appear rather primitive, are stimulating the appearance of entirely new paradigms for learning and research that could not only sweep aside the traditional campus-based, classroom-focused approaches to higher education but seriously challenge the conventional academic disciplines and curricula. For the longer term who can predict the impact of exponentiating technologies on social institutions such as universities, corporations, or governments, as they continue to multiply in power a thousand-, a million-, and a billion-fold?

To be sure, there will be continuing need and value for the broader social purpose of the university as a place where both the young and the experienced can acquire not only knowledge and skills, but the values and discipline of an educated mind, so essential to a democracy; an institution that defends and propagates our cultural and intellectual heritage, even while challenging our norms and beliefs; the source of the leaders of our governments, commerce, and professions; and where new knowledge is created through research and scholarship and applied through social engagement to serve society. But, just as it has in earlier times, the university will have to transform itself once again to serve a radically changing world if it is to sustain these important values and roles.

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Appendix D

The Duderstadts and the Machine

J. J. Duderstadt

Anne and I sometimes view it as both meaningful and ironic that our lives should span almost exactly the computer age. When we were born in the early 1940s, the digital computer was just beginning to appear as part of the nation's wartime efforts, with developments primarily driven by the needs of the Manhattan project and the subsequent development of nuclear technology.

Actually, many of our activities really have not changed very much. Cars and planes are not much faster. Our roads and buildings and cities look pretty much the same. We still depend on energy from oil, gas, and coal (unfortunately). Health care? Some progress in life expectancy, but the major impact of biomedical research is still ahead. We did make it to the moon, but then we stopped. We still haven't blown ourselves up with atomic energy, but it also hasn't made the deserts bloom. And I should confess that the impact of my early work on testing nuclear-powered rocket engines designed for a manned mission to Mars or advanced forms of nuclear power such as laser-driven thermonuclear fusion remain only a remote possibility for the distant future.

But before we conclude that technological change over the past 50 years is no big deal, let me offer another personal perspective. While at Yale in the 1960s I had the opportunity to run a couple of programs on their huge ($2.5 million) IBM 7090 computer. This machine was able to achieve an amazing 40,000 flops (floating point operations a second, the way that one measures computer speeds). Impressive? Not so much.

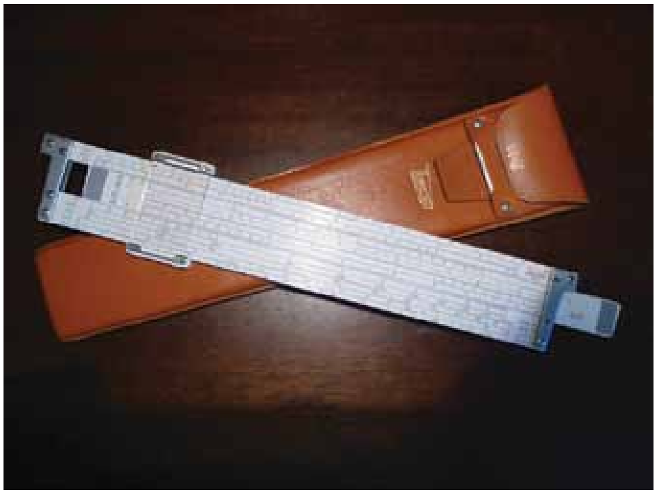
My next computer encounter came in my first job, analyzing the test design of the nuclear powered rocket engines being developed at Los Alamos as part of the Rover Project, aimed at developing the propulsion systems that would eventually power a manned mission to Mars. Here most of my work was based on slide-rule calculations augmented by an occasional simulation using a mockup of electrical circuits (an analog computer).

My first real exposure to big time computing was at the Lawrence Livermore Laboratory in 1973 where I was working on the development of laser-driven thermonuclear fusion. Here I was allocated an hour a day on one of their CDC 7600 supercomputers, capable of 10 million operations a second and 1,000 times faster than the IBM computer at Yale. Fast forward to today, when I am part of a nuclear research project that utilizes the Summit supercomputer at Oak Ridge, currently the fastest in the world at 20 million-billion operations per second, and we are preparing software to run on the next generation computers that will run at a billion-billion operations a second, which has just been announced for 2020 as the El Capitan supercomputer at LLNL.

What is the point of this history? Over the past 50 years, the power of computer technology has increased by a one trillion-fold! That is, the characteristics of computing hardware–speed, memory, bandwidth–have been and are likely to continue increasing by factors of 100 to 1,000 every decade!

Although many technologies have transformed the course of human history, the pace and impact of digital information technology is unprecedented. In little more than half a century, we have moved from mammoth computer temples with the compute power of a digital wristwatch to an ecosystem of billions of microelectronic devices, linked together at nearly the speed of light, executing critical complex programs with astronomical quantities of data. But beyond the impact on scientific work, the influence of this technology on our personal lives has been profound.

To illustrate this, in the next several pages we



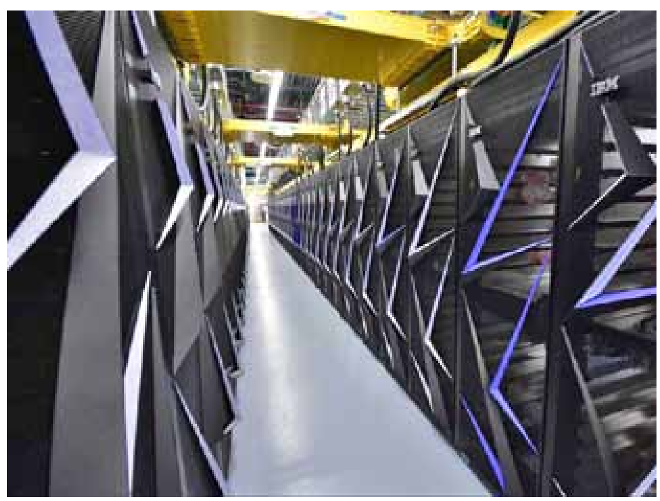
K&E Sliderule

Part of ENIAC at UM (the first U.S. computer)

H-P 35 Pocket Calculator

Yale IBM 7090 Computer

Lawrence Livermore CDC 7600



Oak Ridge Summit Supercomputer

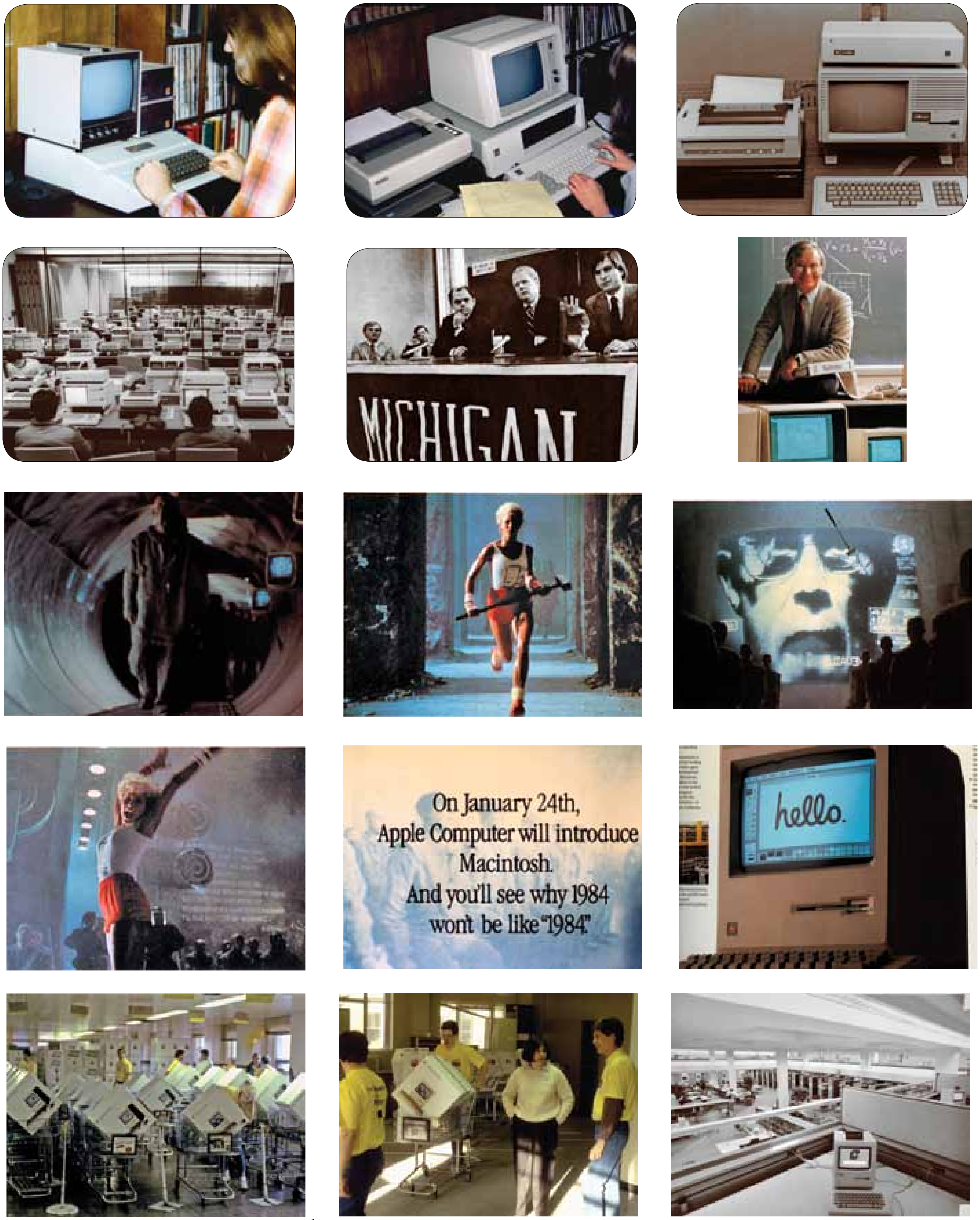
have illustrated the impact of computers on the lives of the Duderstadt family. During the 1970s, we were still using archaic tools like slide-rules, although the appearance of the HP-35 hand calculator (costing $395) was impressive. However in the late 1970s I was persuaded to teach a course using the new Apple II computers, and as an experiment, I brought one of them home to see how our daughters would respond. Needless to say, they took to these personal computers like ducks to water, evolving next to the IBM PC and then continuing to use for their homework and their entertainment whatever computers where popular at the time. These tools, desktop and laptop computers, iPhones and iPads, continue to be important parts of their lives through their college years and into their careers and with their children. In fact our role as grandparents has become that of the family computer store.

Anyway, back to the story. When I became dean, this personal experience with small computers convinced me that they would become an important part of both higher education and professional practice, particularly when linked together in a network. Hence, I strongly encouraged several of our engineering faculty, led by Dick Phillips and Dan Atkins, to develop a powerful network of personal computers for our engineering school, the Computer Aided Engineering Network or CAEN, which continues today as one of the most powerful local networks in the world. This effort was assisted both by the support of major funding from companies such as General Motors as well as by strong relationships with leading companies such as Apple, IBM, and Hewlett-Packard. Michigan actually became a test site for each new generation of these computers, e.g., the Apple Lisa in the early 1980s, and then the MacIntosh in 1984. When I was provost, we launched a massive relationship with Apple to provide opportunities for acquiring personal computers at low discount prices to all Michigan students, faculty, and staff.

But Michigan's impact went far beyond this. At Michigan we were very good at building networks linking together computers such as the MERIT system and we had superb leaders such as Eric Aupperle at MERIT and Douglas Van Houweling as UM's CIO. So when the government put out a request-for-proposal in 1985 to build a national network to link scientists to computers (called NSFnet), MERIT joined with IBM and MCI under Van Houweling's leadership to design and build it. We were fortunate to select a communication protocol developed by the defense industry (TCP-IP) that allowed our network to expand very rapidly, increasing at a rate of 10% a month! As this network became larger and larger, the federal government asked us to add in other networks to create an "internetwork". Perhaps you have already guessed where I'm headed: this UM-IBM-MCI project became the Internet, which we managed until 1993 when industry began to take it over. But I'm not through yet…

In the mid 1990s, we received another grant from the National Science Foundation to develop a digital library. (We already had the experience of developing the JSTOR library for the Mellon Foundation.) Among the student working on this project was a young computer engineering major named Larry Page. (I bet you're already ahead of me again.) Page went on to graduate school at Stanford (also part of the NSF digital library project), where he and Serge Brin developed the Page-Rank algorithm that was the key to the Google search engine. In 2004 Page returned to Michigan and offered to have Google digitize our entire library (all 8 million volumes), which would become the nucleus of a major book search service by Google. Unfortunately Google couldn't figure out how to make money with Google Books, so they gave it to Michigan, and we joined with 80 other universities (including Yale) to create the HathiTrust ("hathi" means elephant in Hindi), currently the largest digital library in the world with 18 million volumes, with over 5 million already opened for full text access.

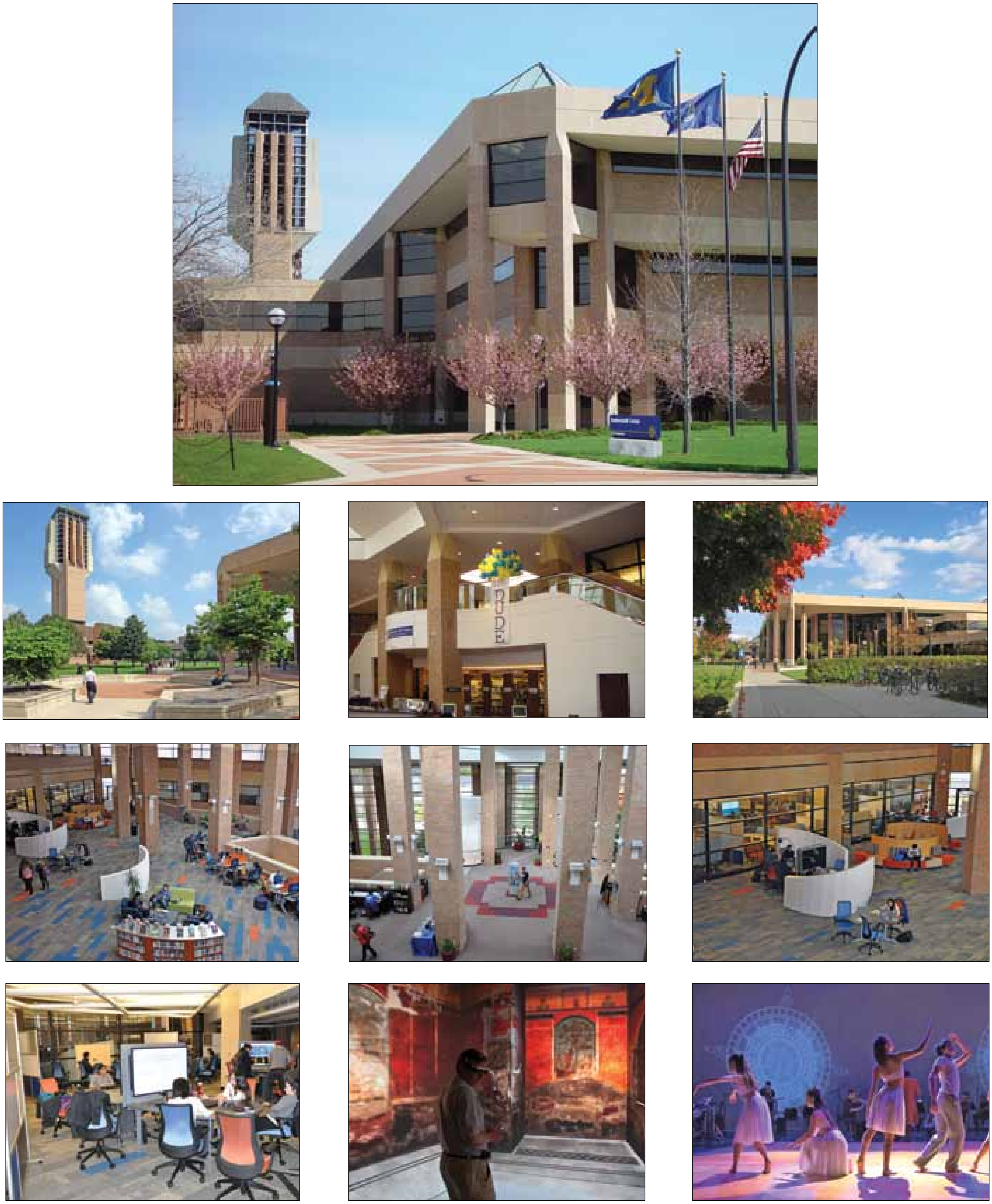
The opening of the Media Union in 1996 was a significant and tangible commitment by the University to provide students and faculty with access to some of the most sophisticated and transformational tools of the emerging digital revolution for creativity. he fundamental purpose of the Media Union was to provide the North Campus schools (Art, Architecture, Music, and Engineering) with access to the rapidly evolving technologies that would change both their disciplines and their educational paradigms. Although all of the schools were exploring the impact of computer technology, the Internet was still relatively new, and the



Jim's personal history of computing, from sliderules to supercomputers
to personal computers to Apple Lisa and Mac to Jim's current office.

The Duderstadt family has grown up with computers...

During the 1990s and beyond, we continued to keep Michigan in a leadership role with "cyberinfrastructure"...hardware, software, and talented people!



The Media Union (later named the Duderstadt Center) provided
state of the art cyberinfrastructure environments for students

transition of documents from physical books to digital libraries (and into the "cloud") was just beginning. It was also intended as an innovation commons, where students from the various North Campus disciplines (along with those from Central Campus venturing into the "north country") could join together to learn and create.

The University retained the architectural firm descended from the famous architect, Albert Kahn, who had designed much of the University campus in the early 20th century, as well as many of the leading buildings in Detroit. The design team of deans, faculty, and staff responsible for the program of the new facility envisioned it as more akin to the MIT Media Lab for students and faculty of the North Campus academic programs. It was designed as a high-tech collection of studios, laboratories, workshops, performance venues and gathering and study space for students. Its original program statement in 1993 portrayed it as an Internet portal to the world (since the Internet was still rather new at that time). It was designed asa place intended for collaboration and innovation in teaching and learning, a place where students, faculty, and staff could access a technology-rich environment, a place open to all "who dared to invent the future".

Although the new facility initially provided space for the library collections of the College of Engineering and the Schools of Art and Architecture, its function has a "traditional" book-based library was never a major part of the longer term vision. After all, with the appearance of massive digitization of written documents, books would rapidly disappear into the "cloud", and librarians would become informationists guiding searches in cyberspace.

More specifically, the resulting 250,000 square foot facility, looking like a modern version of the Temple of Karnak, contained over 1,000 advanced computer workstations for student use. It had thousands of network jacks and wireless hubs for students to connect their own laptops to work throughout the building or in its surrounding plaza and gardens during the summer. There was a sophisticated teleconferencing facility, design studios, visualization laboratories, and a major virtual reality complex. Since art, architecture, music, and theater students worked side-by-side with engineering students, the Media Union contained sophisticated recording studios and electronic music studios. It also had a state-of-the-art sound stage for digitizing performances, as well as numerous galleries for displaying the results of student creative efforts. To serve the unique needs of students and facutly in thse areas, the Media Union was designed to operate 24 hours a day, seve days a week, so that students would have roung-the-clock access to its f acilities.

The Media Union provided unique "commons" facilities, gathering places that support interdisciplinary activities in "making things"–e.g., 3-D objects, virtual reality simulations, new art forms, CGI-based performances, responding to a growing need for both student learning and faculty participation in such activities. In fact, the North Campus schools are recapturing the original vision of the Media Union as an innovation commons or creation space where students, faculty, and staff from multiple disciplines gather to create, invent, design, and even make things (whether objects of art, performances, buildings, or new technologies). Drawing together aspects of hardware and software, inquiry and discovery, tinkering and invention, and creativity and innovation, experimentation and performance, the Media Union provides tremendous interactive playground for imaginative scholars and students. The tools in these facilities are so easy to use that ideally they become natural extensions to everyday activity. For example, an artist , an engineer, and a choreographer should be able to think up a new staging for a performance together, sketch it out in three dimensions on a computer, then show it off and discuss it in real time with colleagues both here and across the world, all without noticing the complex technology that allows them to collaborate.

This model of "creativity and innovation" commons facilities that enable faculty members and students from diverse schools to work together is now being propagated to other parts of the University, including the arts and humanities, social sciences, and the natural sciences and biomedical programs.

Over the past two decades since it opened, this facility "full of unknowns" has become the home for a large and evolving collection of new information and communications technologies far beyond the resources that any one school or college could acquire and maintain. The Media Union's collection of digital assets and resources requires constant renewal with the latest versions of software and hardware, and an expert team of professionals who enable U-M users to get up-to-speed and use them productively for innovative research and teaching. The Media Union rapidly became one of the most active learning spaces in the University, providing thousands of students with 7x24 hour access to rich resources including libraries, advanced technology, workshops, performance venues, and high quality study and community gathering spaces. The center has evolved into an innovative center for discovery, learning, invention, innovation, demonstration, and deployment utilizing state-of-the-art technologies and facilities and assisted by expert staff. In a sense, it serves as a new form of public good, an innovation commons, where students and faculty would come to work together with expert staff mentors to develop the skills and tacit learning acquired through studios, workshops, performance venues, and advanced facilities such as simulation and immersive environments. The Media Union encourages experimentation, tinkering, invention, and even play as critical elements of innovation and creative design.

Rationalizing significant investments in cutting-edge resources by enabling free access to a shared, expertly supported collection of assets has enabled a widespread culture of innovation in digital technologies at the U-M. Students and faculty are free both to envision and to lead, hands-on, change in disciplines being transformed by the digital revolution – from engineering, the performing and design arts, and medicine, to economics and government.

In 2004, in keeping with a long-standing tradition of naming an appropriate building after each former president, the Media Union was renamed the James and Anne Duderstadt Center, or more commonly known to students simply as “the Dude”. Perhaps one student best captured the role of the center when asked to explain its purpose as: “The Dude is the place you go to make your dreams come true!”

So what’s next? Who knows? As we look even further into an unknowable future, the possibilities and uncertainties become even more challenging. Attempting to predict the future is always a hazardous activity. We generally overestimate change in the near term and underestimate it for the longer term, in part because we usually tend to extrapolate what we know today into a future that becomes increasingly beyond our imagination. It is very difficult to peer over the horizon. But there are some trends apparent today that will almost certainly influence the longer term that already raise many questions.

How will wealth be created and value added in this global, knowledge-driven economy? Will increasingly robust communications technologies (always on, always in contact, high-fidelity interaction at a distance) stimulate the evolution of new types of communities (e.g., self-organization, spontaneous emergence, collective intelligence, “hives”)? Suppose info-bio-nano technologies continue to evolve at the current rate of 1,000 fold per decade. Can we really prepare today’s kids for the world of several decades from now when technologies such as neural implants, AI agents (“mind children), and such may actually exist? During the 20th century, the life expectancy in developed nations essentially doubled (from 40 to 80 years). Suppose it doubles again in the 21st century?

For the longer term, who can predict the impact of exponentiating technologies on social institutions such as universities, corporations, or governments, as they continue to multiply in power a thousand-, a million-, and a billion-fold? Imagine what might be possible if all of these elements are merged, i.e., Internet-based access to all recorded (and then digitized) human knowledge augmented by powerful search engines and AI-based software agents; open source software, open learning resources, and open learning institutions (open universities); new collaboratively developed tools (Wikipedia II, Web 2.0); and ubiquitous information and communications technology (e.g., inexpensive network appliances such as iPhones, iPads, or netbooks). In the near future it could be possible that anyone with even a modest Internet or cellular phone connection will have access to the recorded knowledge of our civilization along with ubiquitous learning opportunities and access to network-based communities throughout the world (perhaps even through immersive environments such as Second Life).

Imagine still further the linking together of billions of people with limitless access to knowledge and learning tools enabled by a rapidly evolving scaffolding of cyberinfrastructure, which increases in power one-hundred to one thousand-fold every decade. This hive-like culture will not only challenge existing social institutions–corporations, universities, nation states, that have depended upon the constraints of space, time, laws, and monopoly. But it will enable the spontaneous emergence of new social structures as yet unimagined–just think of the early denizens of the Internet such as Google, Facebook, Wikipedia, …and, unfortunately, Al Qaeda. In fact, we may be on the threshold of the emergence of a new form of civilization, as billions of world citizens interact together, unconstrained by today's monopolies on knowledge or learning opportunities.

Perhaps this, then, is the most exciting vision for the future of knowledge and learning organizations such as the university, no longer constrained by space, time, monopoly, or archaic laws, but rather responsive to the needs of a global, knowledge society and unleashed by technology to empower and serve all of humankind. And all of this is likely to happen during the lives of today's students. These possibilities must inform and shape the manner in which we view, support, and lead higher education. Now is not the time to back into the future.

Appendix E

Biography Summaries of UM Leadership

Daniel Atkins

Daniel E. Atkins (Emeritus W.K. Kellogg Professor of Information and Professor of Electrical Engineering and Computer Science at the University of Michigan (UM)). Atkins's early career focused on computer architecture including high-speed arithmetic methods now widely used in modern computers, as well as the design and construction of application-specific experimental machines.

He later focused on pioneering interdisciplinary research on cyber-enabled distributed knowledge communities including collaboratories and digital libraries applied to both scientific research and education.

He has served as Dean of Engineering, Founding Dean of the School of Information, and Associate VP for Research at UM, as well as the inaugural director of the Office of Cyberinfrastructure at the National Science Foundation (NSF). He chaired the Blue Ribbon Panel on Research Cyberinfrastructure for the NSF that became an international roadmap for initiatives on cyber-enabled research in the digital age.

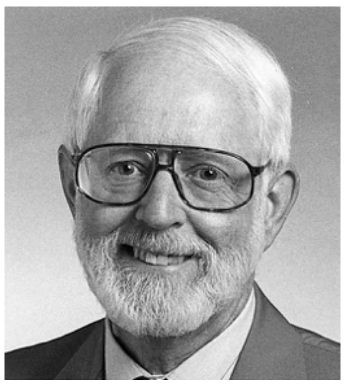
He has chaired or served on many advisory board for government, academia, philanthropy, and industry. Professor Atkins is a member of the National Academy of Engineering. Douglas Van Houweling (Founder of NSFNET and Internet 2)

Eric Aupperle

Eric Aupperle (Founder and Leader of the Merit Computer Network)

Eric Aupperle earned B.S. degrees in electrical engineering and engineering mathematics in 1957, an M.S. degree in nuclear engineering in 1958, and a professional degree, Instm.E. in computer information and control engineering, in 1964, all from the University of Michigan. He joined the University of Michigan faculty in 1963 as an assistant research engineer at the Cooley Electronic Laboratory and as a lecturer in the Department of Electrical and Computer Engineering. He was promoted to associate research engineer in 1963, research engineer in 1967, and research scientist in 1974. His lectureship appointment continued through 1988.

Mr.Aupperle's work at the Cooley Electronic Laboratory included a variety of government and industry funded research projects involving electronic devices and later, computers. His courses included electrical engineering and computer topics at both the undergraduate and graduate levels. He also organized and taught week-long summer courses in the College of Engineering's Summer Short Course program during much of this period. In the fall of 1969, Mr. Aupperle joined Merit Computer Network as project leader to oversee the technical implementation of a computer network linking the academic computer systems of Michigan State University, the University of Michigan, and Wayne State University. Merit's initial network was activated in stages and formally dedicated in May 1973. This network, now known as MichNet, has evolved ever since and, today, is the most extensive and advanced Internet infrastructure in Michigan. Mr. Aupperle was appointed director of Merit in 1974 and president in 1988, a position he held until July 2001. His leadership of Merit was highlighted by the implementation of the National Science Foundation's nationwide NSFNET from 1987-95 in partnership with IBM and MCI. The successful NSFNET initiative is credited as a critical factor in the development of the Internet.



Brice Carnahan

Brice Carnahan, Ph.D., professor of chemical and metallurgical engineering, retired from active faculty status on May 31, 2001, following a 41-year career in the College of Engineering.

Professor Carnahan received his B.S. (1955) and M.S. (1956) degrees from Case Institute of Technology and his Ph.D. degree from the University of Michigan in 1965. He joined the University of Michigan faculty as a lecturer in 1960 and was promoted to instructor in 1963, assistant professor in 1965, associate professor in 1968, and professor in 1970.

From 1959-65, Professor Carnahan was technical director of the Ford Foundation project, "Computers in Engineering Education," and associate director of the NSF project, "Computers in Engineering Design Education." Since 1960, he has been at the forefront of computer applications and computing for which he has received national recognition. In 1969, Professor Carnahan co-authored the landmark text Applied Numerical Methods. For much of his career, he shared responsibility for digital computing courses for all engineering freshmen, impacting some 30,000 students. Twenty-seven different editions of his two course texts have been published.

Lynn Conway

Lynn Conway

Professor Conway received her B.S. and M.S.E.E. degrees, in 1962 and 1963, respectively, from Columbia University. Between 1964-85, she worked at IBM, Memorex Corporation, Xerox Palo Alto Research Center, and at the Defense Advanced Research Projects Agency (DARPA), with service as a visiting associate professor at M.I.T. in 1978. She joined the University of Michigan in 1985 as professor of electrical engineering and computer science and associate dean of the College of Engineering.

At IBM, Professor Conway contributed major innovations to super computer system architecture. At Xerox, she became internationally known as a pioneer of microelectronics for innovations in design methods that influenced VLSI chip design worldwide. She also co-authored the classic textbook, Introduction to VLSI Systems and developed the "MOSIS" system, a national infrastructure for rapid prototyping of VLSI chips by universities and research organizations. Later, at DARPA, she was the technical architect and leader of planning for the defense department's Strategic Computing Initiative, a major research program aimed at innovation in machine intelligence technology.

As associate dean in the College of Engineering, Professor Conway contributed to many research and instructional initiatives during the period of rapid expansion of the College of Engineering on North Campus in the late 1980s and early 1990s, including leading the college's efforts in development, planning, and design of the Media Union. In recent years, she focused on the emerging area of visual communications and control, leading to five U.S. patents for her inventions.

Among the many awards Professor Conway has received during her 35-year career are the Wetherill Medal of the Franklin Institute, the Meritorious Achievement Award from the Secretary of Defense, the National Achievement Award of the Society of

Women Engineers, an honorary doctorate from Trinity College, election as a fellow of the Institute of Electrical and Electronics Engineers, and election to the National Academy of Engineering.

Paul Courant

Paul Courant is the Harold T. Shapiro Collegiate Professor of Public Policy, Arthur F. Thurnau Professor of Economics and Information and a Presidential Bicentennial Professor at the University of Michigan. Courant has served as provost and executive vice president for academic affairs, as university librarian and dean of libraries, as associate provost for academic and budgetary affairs, as chair of the Department of Economics, and as director of the Institute of Public Policy Studies (predecessor of the Ford School). He served as a senior staff economist at the Council of Economic Advisers from 1979 to 1980. Courant has authored half a dozen books and more than six dozen papers covering a broad range of topics in economics and public policy.

More recently, his academic work has focused on economic and policy questions relating to universities, libraries and archives, and the effects of new information technologies and other disruptions on scholarship, scholarly publication, and academic libraries. He was a founding board member of both the HathiTrust Digital Library and the Digital Public Library of America, and is a member of the advisory committee of the Authors Alliance. Courant holds a bachelor's in history from Swarthmore College (1968), a master's in economics from Princeton University (1973), and a doctorate in economics from Princeton University (1974).

James Devaney

James DeVaney (Associate Vice Provost for Academic Innovation and Director of the Office of Academic Innovation). DeVaney provides leadership for academic innovation at the University of Michigan and strategic initiatives that span the university in his role as Associate Vice Provost for Academic Innovation. He provides strategic and operational leadership for the Office of Academic Innovation where he is responsible for developing a sustainable model for academic innovation and fostering a culture of innovation in learning at U-M. The Office of Academic Innovation works with innovators throughout the U-M community to advance learning through initiatives focused on curricular innovation, education at scale, public engagement, and diversity, equity and inclusion.

Prior to his role at U-M, James Devany was a senior director at Huron Consulting Group where he co-founded the firm's global education and digital education practices. Previously, he lived in the United Arab Emirates where he established the firm's presence in the MENA region. James has worked with and provided strategic counsel to more than 50 universities in more than 15 countries across the Middle East, North Africa, Europe, Australia and North America. In addition to world-class research universities, James has advised startup colleges and universities, new educational ventures, international branch campuses, government agencies, national libraries, museums, think-tanks, social enterprise organizations and K-12 focused nonprofits. He received a BBA and MBA from the UM Ross Business School and a MS Degre from the UM Ford School of Public Policy.

Dan Fessahazion

Randy Frank

James Hilton is Vice Provost for Academic Innovation and Dean of libraries at the University of Michigan, where he leads one of the world's largest and most innovative library systems, and spearheads the development of campus-wide strategies, policies and programs around educational technology and other cross-campus academic innovation initiatives.

James Hilton

Prior to his current appointment, Dr. Hilton served as Vice President and Chief Information Officer at the University of Virginia from 2006 until 2013. From 2001 to 2006 he was the Associate Provost for Academic Information and Instructional Technology Affairs at the University of Michigan, and served as the Interim University Librarian for one year in 2005. He was a member of the faculty at the University of Michigan in the Psychology Department where he served as the Chair of Undergraduate Studies between 1991 and 2000. He is a three-time recipient of the LS&A Excellence in Education award, an Arthur F. Thurnau Professor, and recipient of the Class of 1923 Memorial Teaching Award. He has published extensively in the areas of information technology policy, person perception, stereotypes, and the psychology of suspicion.James Hilton received a B.A. in Psychology from the University of Texas at Austin in 1981, and a Ph.D. in Social Psychology from Princeton University in 1985.

John King

John King

Gary Olson Gary M. Olson, Ph.D., Paul M. Fitts Collegiate Professor of Human-Computer Interaction and professor of information, School of Information, and professor of psychology, College of Literature, Science, and the Arts.

Professor Olson received his B.A. degree from the University of Minnesota in 1967, and his M.A. and Ph.D. degrees from Stanford University in 1968 and 1970, respectively. Following service in the U.S. Naval Reserve from 1970-73, he served two years on the faculty of Michigan State University. Professor Olson joined the University of Michigan as an assistant professor of psychology in 1975, and was promoted to associate professor in 1977 and professor in 1984. He joined the School of Information as professor and as associate dean for research in 1995. He was named the Paul M. Fitts Collegiate Professor of Human-Computer Interaction in 2001.

Wiliam Martin

William Martin

Professor Olson was the founding director of the Collaboratory for Research in Electronic Work (CREW), and oversaw its migration from an OVPR incubator

Gary Olson

unit into a research center in the School of Information. In his role as associate dean, he was instrumental in reshaping the School of Information after its change in scope and mission in 1996, leading to the revitalization of the doctoral program, expansion of the base of externally funded research, and the development of the Human-Computer Interaction Program. Professor Olson has published over 120 articles and book chapters and is the leading authority on how information technology can be used to support work when participants are in different locations. In 2006, he was awarded (jointly with Judith S. Olson) the CHI Lifetime Achievement Award from SIGCHI (Special Interest Group on Computer-Human Interaction) of the Association for Computing Machinery, acknowledging his leadership and lifetime impact on the field of human computer interaction and contributions to the development of the science of collaboration.

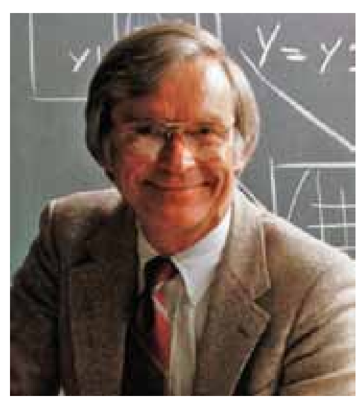
Judy Olson

Judy Olson Judith Spencer Olson, Ph.D., Richard W. Pew Collegiate Professor of Human Computer Interaction, professor of information, and associate dean for academic affairs, School of Information, professor of computer and information systems, Stephen M. Ross School of Business, and professor of psychology, College of Literature, Science, and the Arts, will retire from active faculty status on June 30, 2008.

Professor Olson received her B.A. degree from Northwestern University in 1965 and her Ph.D. degree from the University of Michigan in 1969. Following a postdoctoral fellowship at Stanford University, she joined the University of Michigan faculty in 1970 as a lecturer in the Department of Psychology, where she was promoted to assistant professor in 1972 and associate professor in 1976. In 1980, she left the University to work at Bell Laboratories but returned to the faculty in 1983 as associate professor of computer and information systems in the Stephen M. Ross School of Business and adjunct associate professor of psychology. She was promoted to professor of computer and information systems and professor of psychology in 1990 and was named professor of information in the School of Information in 1995. She was appointed Richard W. Pew Collegiate Professor of Human-Computer Interaction in 2001 and has served as associate dean for academic affairs since 2006.

Professor Olson is recognized as a leading scholar in the fields of human computer interaction and collaboration. She has an excellent record of securing research funding, has published over 110 articles and book chapters, and has served on a number of journal editorial boards. In 1978, she received the AMOCO Award for Outstanding Teaching, recognizing her contributions as a teacher and mentor of undergraduate students. In 2006, she was awarded (jointly with Gary M. Olson) the CHI Lifetime Achievement Award from SIGCHI (Special Interest Group on Computer-Human Interaction) of the Association for Computing Machinery, acknowledging her leadership and lifetime impact on the field of human-computer interaction and contributions to the development of the science of collaboration.

Dick Phillips



Dick Phillps

Richard L. Phillips, Professor of Aerospace and Electrical Engineering and Computer Science, retired from active faculty status as of February 7, 1987.

Professor Phillips

received the B.S. degree in aeronautical engineering and mathematics in 1956, and the M.S. degree in aeronautical engineering in 1957, both from The University of Michigan. From 1957-58 he worked at the Space Technology Labs (now TRW) in Los Angeles. He returned to Ann Arbor in 1958, where he spent three years at Bendix Systems Division and three years at the University of Michigan Aircraft Propulsion Laboratory. He was awarded the Ph.D. degree in aeronautical engineering from The University of Michigan in 1964. His Ph.D. thesis, which involved a study of A.C. and D.C. arc heaters and fundamental arc phenomena, had a major impact on the field, and led to his receiving a postdoctoral fellowship at the Elektrophysikalisches Institute, Technichen Hochschule, Munich, Germany, and the University of Liverpool in England. His thesis work also marked the beginning of his interest in computers.

Professor Phillips was appointed assistant professor of aerospace engineering in 1965, promoted to associate professor in 1968, and to professor in 1974. He received an additional appointment as professor of electrical engineering and computer science in 1985. Although in the early years of his academic career he continued his research in the field of electric arc phenomena, he eventually became active in computer graphics hardware and software development, and computer-animated film production. As a result of his very innovative work, he became a leading figure in these areas.

He served as associate director of the Computing Center in 1973, as chairman of the university committee on computer policy and utilization from 1976-79, as founder and first director of the Computer Aided Engineering Network (CAEN) in 1982, chair of the CAEN executive committee from 1983-86, and acting director of the Center for Information Technology Integration in 1986. He has also been instrumental in developing cooperative programs with Apple Computer and Apollo Computer.

He has lectured throughout the world, consulted widely, and published a number of articles. His is on the editorial boards of four computer journals and is a member of a number of professional societies in his field.

The Regents now salute this distinguished educator and researcher by naming Richard L. Phillips Professor Emeritus of Aerospace Engineering and Professor Emeritus of Electrical Engineering and Computer Science.

James Wilkes


James Wilkes

James O. Wilkes, Ph.D., professor of chemical engineering, will retire from active faculty status on May 31, 2000, following 40 years of teaching, research, and service at the University.

Born in Southampton, England, Professor Wilkes received his B.A. degree from the University of Cambridge in 1954 and his M.S.E. and Ph.D. degrees from the University of Michigan in 1956 and 1963, respectively. He served on the faculty at the University of Cambridge from 1957-60 and joined the University of Michigan in 1960 as an instructor. He was promoted to assistant professor in 1963, associate professor in 1966, and professor in 1970.

Professor Wilkes was a pioneer in the numerical solution of partial differential equations and his research interests have focused on this area. He has been a prolific author or co-author of popular textbooks throughout his career, from the first, Applied Numerical Methods (Wiley), in 1969, to the most recent, Fluid Mechanics for Chemical Engineers (Prentice-Hall), in 1999. He has chaired or co-chaired 22 doctoral committees.

For extended periods beginning in 1967 and continuously from 1981-97, he shared responsibility for all required freshman-computing courses in the College of Engineering, which directly impacted perhaps 30,000 Michigan engineering freshmen. In the classroom, Professor Wilkes specialized in fluid mechanics and numerical methods. He has been recognized many times for his dedicated classroom teaching, beginning in 1980 as the first recipient of the College of Engineering Excellence in Teaching Award. In 1987, he received the highest University award for classroom teaching, the Amoco Good Teaching Award, and in 1989, he was named an Arthur F. Thurnau Professor.

Professor Wilkes served as chair of the chemical engineering department from 1972-77, as a member of the College of Engineering Executive Committee from 1985-89, as assistant dean for admissions in the college from 1990-94, and as assistant- or co-editor of two professional chemical engineering journals. His outstanding contributions to the department, the College of Engineering, the University, and his profession are widely recognized and appreciated by his students and colleagues.

John Price Wilkins

John Price Wilkin, M.A., M.L.S., associate university librarian for library information technology and publishing and librarian, University Library, retired from active faculty status on August 2, 2013.

John Price Wilkin

Mr. Wilkin received his B.A. degree from Antioch College in 1979, his M.A. degree from the University of Virginia in 1980, and his M.L.S. degree from the University of Tennessee in 1986. He joined the University of Michigan faculty as an assistant librarian in 1986, and was promoted to associate librarian in 1988. Mr. Wilkin then served as the systems librarian for information services at the University of Virginia from 1992-94. He returned to the University of Michigan as a librarian in 1994.

A pioneer in the field of library information technology, Mr. Wilkin held numerous key leadership positions including head of the Humanities Text Initiative, head of the Digital Library Production Service, interim co-university librarian, associate university librarian for library information technology and publishing, and executive director of the HathiTrust. He played an instrumental role in the development, negotiation, and execution of the Michigan Digitization Partnership with Google, Inc. This ambitious digitization project has provided scholars and the general public with unprecedented access to the University Library's vast collections. As executive director of the HathiTrust, Mr. Wilkin has led a collaborative consortium of academic and research institutions focused on the long-term preservation of and access to millions of digitized titles from libraries around the world. Mr. Wilkin also taught courses on the application of Standard Generalized Markup Language (SGML) for information organization and retrieval in the School of Information. He received the Library and Information Technology Association/Library Hi Tech Award for Outstanding Communication for Continuing Education in Library and Information Science in 2011.

Professor Douglas Van Houweling received his B.S. degree from Iowa State University in 1965 and his Ph.D. degree from Indiana University in 1974. He joined the University of Michigan faculty as the vice provost for information technology (1984-1995) and an adjunct professor (1985-1995). He was appointed a professor of information in 1996. He also served as the School of Information's associate dean for research and

Douglas Van Houweling

innovation from 2010-14.

Van Houweling was serving as chief information officer at the University of Michigan and chairman of the board of the Michigan Educational Research Information Triad (MERIT), a statewide computing network in Michigan in 1987, when the National Science Foundation awarded MERIT the responsibility for the operation and management of the NSFnet national backbone- the foundation upon which the global Internet was built. During MERIT's seven-year tenure, internet traffic and connectivity grew by more than 400% per year. When the NSFnet project began transitioning the internet backbone to commercial providers in 1992 more than 6,000 networks were connected, including one third of which were outside the United States. Van Houweling made fundamental contributions to the growth of the Internet and in areas related to information systems planning and management, not-for-profit organization management, strategic planning, simulation models of political and public policy processes, economic models of politics, and technology assessment. By 1994, networks in 94 countries were connected and the internet had become a global phenomenon. Van Houweling was also chairman of the Board of Advanced Network and Services Corporation, a not-for-profit organization that enabled the transition of large-scale internet capabilities from the higher education and research realm to commercial reality. From 1997-2010, he served as the president and chief executive officer of Internet2, the national research and education network for the United States.

He has served on numerous boards of Internet companies and educational institutions such as Consortium for Research in Telecommunications Policy and Strategy, the National Research Council Study, and the National Science Foundation. Van Houweling has also frequently consulted with Internet and technology companies and universities including Apple, General Electric Corporation, and IBM Corporation.