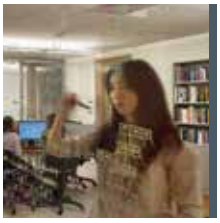
HOW COLLEGES & UNIVERSITIES INVIGORATE CAMPUSES THROUGH **A NEW GENRE OF STEM BUILDINGS**

EYP/

August 2016

/ Table of Contents



/ Authors

Leila Kamal AIA, LEED AP BD+C

Vice President / Design & Expertise

Leila runs EYP's research programs and the development of its expertise in smart, sustainable design. She has been involved in new STEM buildings at Hamilton College, Wheaton College, and the College of the Holy Cross.

Toni Loiacana AIA, NCARB, LEED AP BD+C

Academic Planning & Design

Toni has been designing science and research space for more than a decade. Her work includes the science buildings at the Massachusetts College of the Liberal Arts, Trinity University, and Michigan State University. She is a member of EYP's STEM research team.

Kip Ellis AIA, LEED AP BD+C

Lead Designer

Kip has been a designer and planner for more than 20 years and a specialist in sophisticated science buildings that promote innovative learning and celebrate an institution's unique culture. His projects include the science buildings at the College of the Holy Cross, Franklin & Marshall College, Middle Tennessee State University, Swarthmore College, and the University of New Hampshire.

Charles Kirby FAIA, LEED AP BD+C

Academic Planning & Design

Charles has been designing college facilities for more than 30 years and is a senior member of EYP's STEM research team. His projects include STEM buildings at Hamilton College, Swarthmore College, College of the Holy Cross, and Franklin & Marshall College.

We are 600+ professionals in architecture, engineering, energy, and interior design who collaborate across 15 offices in the United States and Europe to deliver high-performance building design, research, and consulting services. We are the trusted advisors to corporate, government, higher education, healthcare, and science & technology clients. Our award-winning family of practice groups includes sustainable design leader EYP Architecture & Engineering; WHR Architects, healthcare design specialists; and The Weidt Group®, building energy performance specialists.

/ Executive Summary

U.S. colleges and universities have made significant investments during the last decade in science, technology, engineering and mathematics programs (STEM), both to remain vibrant institutions and to help the U.S. compete on the world stage in scientific innovation. Amidst research and reports showing that a third of U.S. post-secondary institutions are struggling financially, many of them see a highly competitive STEM program as a key to their future success and survival.

While many colleges and universities have made progress – bachelor's degrees earned in science and engineering increased nearly 40% from 2000 to 2011 – at 16%, the overall percentage of U.S. post-secondary students earning STEM undergraduate degrees has barely budged. What's more, a still-high percentage of STEM students exit those majors before graduating. As a result, the U.S. continues to have one of the world's smallest ratios of students earning STEM degrees.

However, a small but growing number of institutions have substantially bolstered their STEM programs. They have gone beyond the usual investments – attracting high-powered faculty, upgrading curriculum and increasing marketing to students – and have radically redesigned or built entirely new science and engineering buildings that are very different than the science and engineering facilities of the last 100 years. These buildings have become magnets on campus for STEM and non-STEM majors alike. They are fostering interdisciplinary teaching, flexible laboratories that enhance instruction, safer and more efficient research, and "soft" spaces for informal learning.

Colleges and universities that have made these facility investments range from small liberal arts schools such as Hamilton College (located in Clinton, New York), Trinity University (San Antonio, Texas) and the College of the Holy Cross (Worcester, Massachusetts), to large private universities like New York University. In this article, we examine the factors that drove these and other institutions to radically redesign their STEM classroom buildings. We explore five design practices they used and their impact on student enrollment, faculty hiring, and other important metrics:

- Carefully designed and strategically placed "soft" spaces
- Flexible lab spaces that promote hands-on learning
- Reconfigurable classroom spaces
- Glass walls that put science and engineering on display, create a sense of community, and encourage collaboration
- Research labs that promote efficient and safe research, and better teaching

Designing new STEM buildings in radically different ways can generate significant resistance from faculty and administration, including professors questioning the connection between building design and improved teaching, worries about campus aesthetics, and cost. In this paper, we examine how a number of colleges and universities overcame such opposition and built non-traditional STEM buildings that have revitalized their science and engineering programs.

We also explore formal research studies done by EYP and academic partners on the results of the revamped science and engineering centers at four institutions. In our experience, they pursue seven common goals with their science and engineering center modernizations:

- Creating a welcoming place to congregate, study, and learn
- Advancing student and faculty research
- Making STEM teaching more effective
- Promoting interaction among students and faculty
- Making the institution more competitive in attracting students and faculty
- Enhancing students' interest in and attitude toward STEM
- Creating an environment that is energy efficient, sustainable, and satisfying to occupants

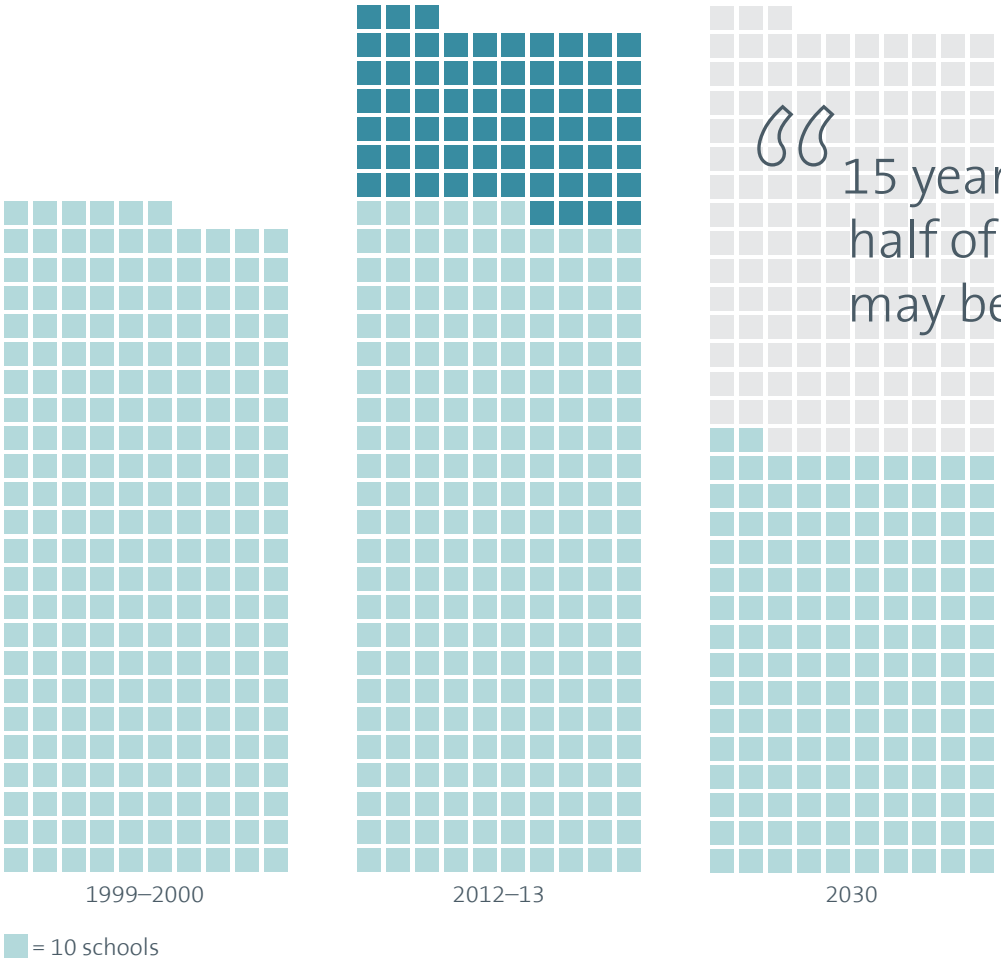
Through our formal research, we have quantified how well universities met those goals, and the role of the buildings in meeting those goals. Finally, we explain the benefits that a number of colleges and universities have gained from significantly revamping their STEM buildings, and how they overcame the barriers to success.

University of Scranton
Loyola Science Center

/ Financial Unease Hits Campus

The financial pressures on many U.S. colleges and universities have been acute since the turn of the century. Following a nearly 30% increase in the number of four-year colleges and universities just since the year 2000,[1] a third of American higher-education institutions were struggling financially, according to a 2012 study by consulting firm Bain & Company and private equity firm Sterling Capital Partners.[2] A follow-up study in 2014 found that while fewer schools were financially unsound, many more were "at risk" of soon getting there. Small private institutions that are not among the elite and depend highly on tuition revenue have the most to worry about, one of the study's authors believes.[3] In contrast, highly selective colleges and universities (because of their pricing power) and institutions with strong endowments (which can serve as "shock absorbers," the study authors said) should have fewer concerns.

THE NUMBER OF FOUR-YEAR COLLEGES AND UNIVERSITIES
GREW BY NEARLY 30% FROM 2000-2012
BUT FUTURE GROWTH IS LESS CERTAIN.



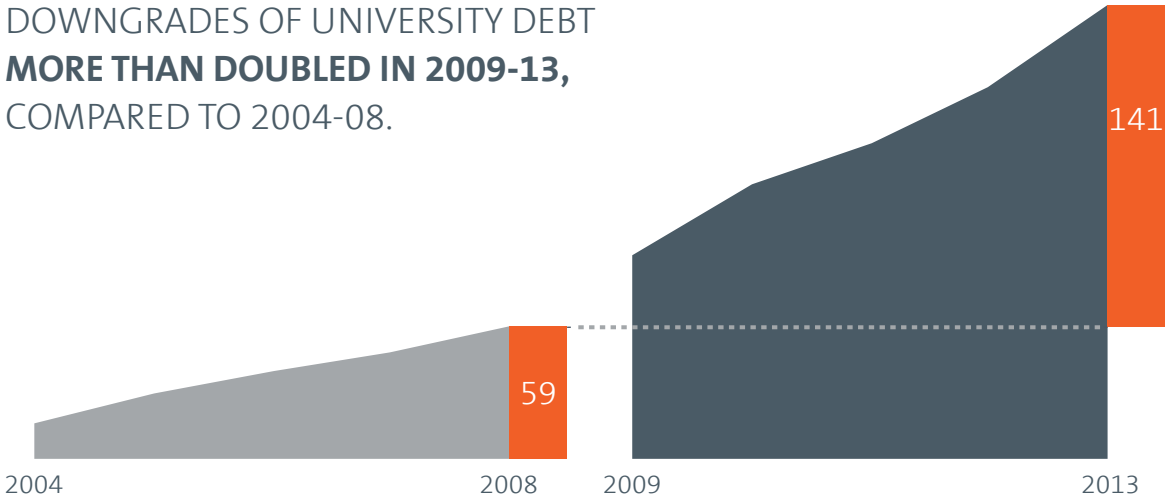
> "15 years from now half of US universities may be in bankruptcy
>
> **Clayton Christensen**
> Harvard Business School

Bain and Sterling Capital haven't been the only ones ringing the alarm bells for U.S. colleges and universities. The U.S. Department of Education and bond rating agency Moody's Investors Service issued separate warnings in 2015. In March of that year, the Department of Education said nearly 560 institutions had been subjected to greater financial oversight (termed "heightened cash monitoring"[4]) between 2011 and 2014, with 69 under "stringent restrictions."[5] And in July 2015, Moody's announced that about 20% of public and private universities would suffer slow or declining revenue gains from weak enrollment and limited pricing flexibility. The Moody's report noted that small, private institutions with less than $200 million in revenue and regional public universities under $500 million faced the greatest stress.[6] Two months later, Moody's predicted the closure rate of small, not-for-profit private and public colleges and universities would triple by 2017 (to 15 a year, or less than 1% of the 2,300 four-year private non-profit and public colleges and universities) and the merger rate would more than double.[7] Between 2009 and 2013, the number of public and private institutions whose debt Moody's had downgraded (141) was more than double the number downgraded in the previous five years and four times more than the number it upgraded. That was a big reversal from the previous nine years.[8]

Some corners of academia itself have issued even more dire warnings about the fate of many U.S. colleges and universities. Last year, 18% of U.S. college and university executives polled by Inside Higher Ed said their institutions were at risk of closing in the coming decades.[9] And Harvard Business School Professor Clayton Christensen – known in the business world for his theory about how digital technologies disrupt industries – has forecasted that as much as half of the nation's universities and colleges may go out of business by 2030. In Christensen's view, online learning will supplant much of the education delivered on campus.[10]

In the face of such intense pressures, many college presidents, management teams and advisers have done extensive soul searching. The challenges to keeping a college competitive are especially great at smaller institutions with smaller endowments.

DOWNGRADES OF UNIVERSITY DEBT
MORE THAN DOUBLED IN 2009-13,
COMPARED TO 2004-08.



Moody's downgrades of public and private universities (cumulative).

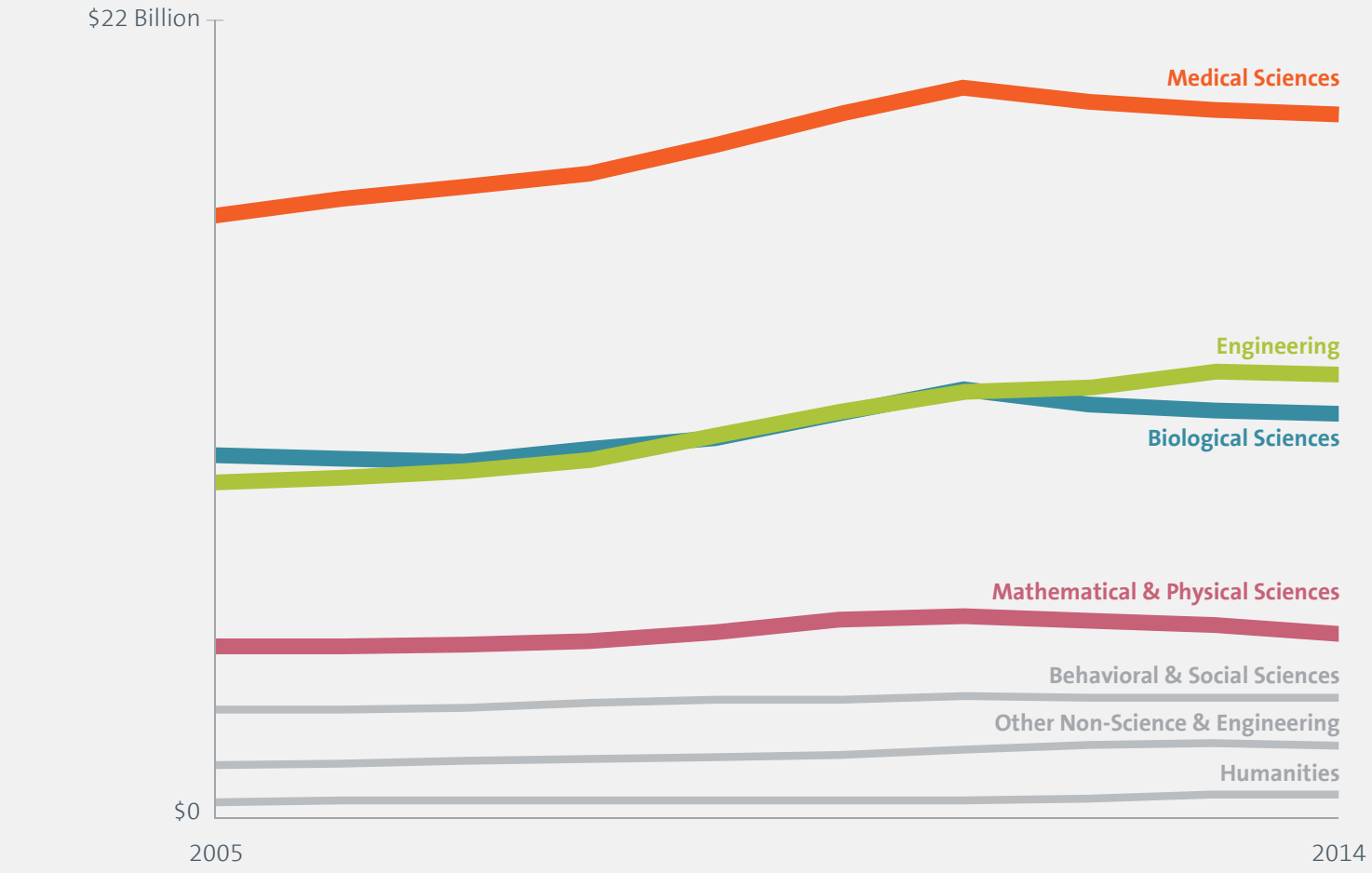
Source: National Center for Education Statistics (1999-2013 data) and Clayton Christensen, Harvard Business School (2030 forecast)

/ A Popular Formula: Focusing on STEM Programs

Colleges and universities have reacted a number of ways: reducing costs, increasing specialization, funding more aggressive marketing to attract students, and pulling tighter on alumni heart strings (in pursuit of their wallets). But during the last 10 years, most colleges and universities have chosen to beef up their STEM programs: the science, technology, engineering and mathematics offerings that have been called key to America's competitiveness.

"There's an overwhelming push from the administration at most universities to build up the STEM fields, both because national productivity depends in part on scientific productivity and because there's so much federal funding for science," John Tresch, a historian of science at the University of Pennsylvania, told *The New York Times* in 2013.[11]

R&D SPENDING ON STEM FIELDS DWARFS UNIVERSITY SPENDING ON NON-STEM FIELDS



Source: National Science Foundation, National Center for Science and Engineering Statistics, Survey of R&D Expenditures at Universities and Colleges.

State governments have also been increasing institutions' appetites for expanding their STEM programs. At least 16 state legislatures have created incentives for public colleges and universities to get students to seek STEM degrees rather than those in the humanities, specifically to reduce the soaring student loan debt. Their thinking is that more employable STEM graduates commanding higher salaries have a better chance of paying back their loans. In fact, a number of salary surveys show that STEM graduates get paid more than humanities majors. One recent survey predicted new engineering graduates would earn about 40% more in 2016 than the average humanities graduate.[12]

National competitiveness and U.S. employer needs have stoked the fire for STEM programs even more. For example, as part of President Obama's U.S. STEM investment program, the National Science Foundation (NSF) committed more than $100 million to undergraduate STEM teaching, with the goal of increasing retention in those majors. The NSF also received $325 million to boost graduate STEM programs, including research fellowships.[13]

College of the Holy Cross
Integrated Science Complex

The research funding that STEM programs can commandeer has been especially enticing to colleges and universities. In 2014, U.S. colleges and universities spent more than $10 billion in R&D in each of these fields: biological sciences, mathematical and physical sciences and engineering. In medical sciences they spent more than $20 billion. In stark contrast, humanities and other non-science and engineering fields spent less than 10% of that amount ($2 billion) annually on R&D.[14]

What's more, it has been far easier for institutions to get government money for STEM research in the last decade. The U.S. government funded more than 60 percent of colleges' and universities' math and physical sciences, biological sciences, and engineering R&D from 2005 to 2014, about triple the percentage it funded for R&D in the humanities.[15]

U.S. colleges and universities have also invested in STEM to meet the demands of a growing number of students enrolling in those majors. Between 1991 and 2012, the number of bachelor's degrees conferred in the natural sciences, mathematics, computer sciences, and engineering soared 64% – nearly 40% just between 2001 and 2012. To meet that demand, many schools spent heavily on their STEM programs.[16]

For example, the University of Colorado's number of science majors rose 5% (or about 1,800 students) between 2010 and 2014,[17] while the number of students majoring in arts and humanities dropped 32% between 2009 and 2013.[18] The university's CFO partly attributed a 14% rise in expenses in the CU system from 2001 to 2014 to "this push to get students to enroll in STEM-oriented programs. ... It's working, but it costs more, and that's one of the reasons why we're seeing an increase in spending."[19]

/ For Some Institutions, STEM R&D and Faculty Have Not Been Enough

While investments in STEM R&D appear to have helped some colleges and universities become more attractive, they may not be enough. Many colleges and universities continue to struggle to build competitive STEM programs that attract both students and faculty. Consider the following:

- Despite the nearly 40% increase in STEM bachelor's degrees conferred between 2000-01 and 2011-12, the percentage of U.S. college graduates with bachelor's degrees in natural sciences, mathematics, computer science and engineering remained essentially the same, at about 16% of all bachelor's degrees.[20] What's more, the percentage of master's degrees conferred in those fields actually declined (from 12.5% to 12.2% of all master's degrees) in that period, while the proportion of doctor's degrees in those disciplines rose, from 13.8% to 15.0% of all doctor's degrees.

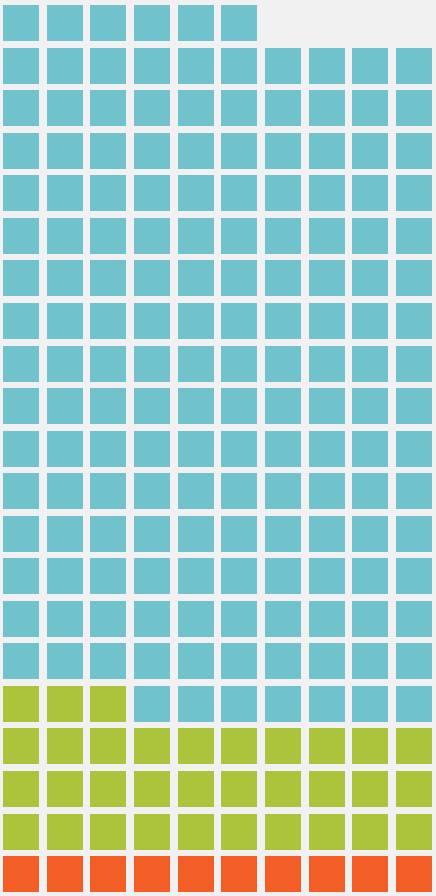
- Investments in STEM programs haven't substantially reduced attrition. Between 2003 and 2009, 48% of STEM students in pursuit of bachelor's degrees and 69% aiming for associate's degrees had left the STEM fields, according to the U.S. Department of Education.[21] In fact, the U.S. has one of the world's smallest ratios of STEM to other bachelor's degrees, according to a 2012 report by the National Science Board.

- Increasing financial aid and easing admission requirements don't guarantee that students will remain STEM majors. A 2015 study by Georgia State University and Oklahoma State University found evidence of the opposite effect: that offering STEM scholarships may actually encourage STEM majors to switch to other majors. The study found that states with merit aid programs actually reduced the number of STEM graduates between 1991 and 2005. The researchers weren't sure why, theorizing that perhaps some students were concerned about having to maintain a grade point average to keep their scholarships.[22]

These trends are worrisome to many colleges and universities, U.S. companies and the government, and alarming to some. A White House report in 2012 said the U.S. will need 1 million more STEM professionals over the next 10 years than are being produced at the current pace.[23] If producing a large number of STEM graduates remains a national priority – and there's no reason to think otherwise in a society of rising technical complexity – these numbers should be alarming. As a share of all bachelor's degrees granted, the U.S. STEM degrees (31% of all U.S. bachelor's degrees in 2008) were running far behind the percentages in countries like China and Japan, where the degrees are more than half the total conferred.[24]

Apparently, offering STEM scholarships and attracting research funding alone are not enough for many colleges and universities to make their STEM programs a magnet for students. What more can they do?

THE LOOMING STEM GRADUATE SHORTAGE



more than
20,600,000
students will graduate from universities from 2012-2022

about
3,300,000
of them will be STEM majors

which is
1,000,000
fewer than we need, according to the White House

= 100,000 graduates

How Some Colleges And Universities Have Created Competitive STEM Programs: Rethinking the Facility

Several dozen U.S. colleges and universities in the last 10 years have gone further than others in making their STEM programs more attractive and competitive. They have done so by investing aggressively – but strategically and innovatively – in their teaching and research buildings.

"Continued reinvestment in facilities is an essential factor for maintaining a university's competition position, both in attracting students as well as faculty," said two Moody's analysts in a 2016 outlook report. It predicted that colleges and universities would continue funding buildings for core academics and classroom structures through debt, gifts, cash flow, and reserves.[25] While Moody's estimated 15% to 20% of colleges and universities must cut costs to remain financially sound, the majority will have the cash "to invest in programs and facilities to sustain their strategic position." Institutions that can't make such investments in their facilities face a "death spiral," said one Moody's analyst.[26]

The Bain/Sterling Capital study offered a similar conclusion. It advises colleges and universities to cut costs in areas "farthest from the core of teaching and research. Cut from the outside in, and build from the inside out."[27] It went on to say that the share of public and private research university spending on administration and support had increased between 1995 and 2010, while spending on instruction (including buildings) had declined.

However, a number of colleges and universities have gotten the message. Research-driven U.S. colleges and universities planned to spend $7.1 billion on new science and engineering research space in fiscal 2014 and 2015, up from $5.5 billion in 2012 and 2013, according to a 2013 NSF study.[28] That money did not include space for medical schools.

Most STEM buildings funded
50-100% through donations

Driven by those factors, many colleges and universities have made sizable investments in new STEM buildings. Here are four examples:

- Hamilton College completed a $47.4 million science center in 2005, the largest construction project in the school's 223-year history. The complex featured more than 100 teaching and research labs, an auditorium and a greenhouse. Hamilton's biannual surveys of enrolled students between 2004 and 2014 have found at least 50% rated the quality of academic facilities as very important in choosing which college to attend.[29]

- The University of Vermont had been losing students to institutions both in its region and others around the country that had better STEM classrooms, labs and studios, said Provost David Rosowsky in a 2014 essay. In 2015, UVM began construction on a $104 million STEM complex (three buildings adding up to more than 250,000 square feet), for completion by 2018. "We simply must make the greatly needed and long-overdue investment in STEM," Rosowsky wrote. STEM buildings "are some of the first facilities students and their parents ask to see on campus tours, and often are the feature that makes or breaks a student's decision on choice of university. ... Science and technology spaces ... are often cited at the top of the list of facilities that drive students' decisions – over residence halls, libraries, and even student unions."[30]

- The University of Mississippi is planning a new $100 million science building. Said associate provost Maurice Eftink: "The new STEM building will be a real game changer for the university. ... We have reached a stage where we are almost maxed out in our ability to provide STEM courses, especially lab courses" in health, engineering, science and math.[31]

- The University of Connecticut is building a $105 million NextGen Hall, targeted for a fall 2016 opening.

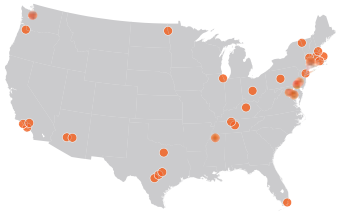
A growing number of colleges and universities are making serious investments in STEM buildings. But while this investment is critical, our experience with more than 20 institutions shows that creating new buildings in the image of the old ones isn't nearly enough.

Mean construction cost for a new science and engineering building **= $75 million**

Hamilton College completed a $47.7 million science center in 2005, the largest construction project in the school's 223-year history.

MEMBERS OF THE COLLEGE STEM BUILDING CENTURY CLUB

NEW COLLEGE SCIENCE BUILDINGS OPENED SINCE 2000 AT A COST OF AT LEAST $100 MILLION (PARTIAL LIST)



College/University	Location	Total Square Footage	Total Cost of STEM/ Science Building	Year Completed
Trinity University	San Antonio, TX	230,000	$127 million	2014
University of Vermont	Burlington, VT	250,000	$104 million	2018
University of Mississippi	Oxford, MS	200,000	$135 million	2018
Northeastern University	Boston, MA	220,000	$225 million	2016
Penn State University	University Park, PA	275,600	$225 million	2012
Florida International University	Miami, FL	225,000	$150 million	TBD
Georgetown University	Washington, DC	154,000	$100 million	2012
Vanderbilt University	Nashville, TN	230,000	$109 million	2016
Columbia University	New York, NY	188,000	$179 million	2010
George Washington University	Washington, DC	500,000	$300 million	2014
University of Massachusetts at Boston	Boston, MA	220,000	$182 million	2015
Arizona State University	Tempe, AZ	327,256	$160 million	2012
Temple University	Philadelphia, PA	247,000	$137 million	2014
Loyola Marymount University	Los Angeles, CA	100,000	$110 million	2015
Chapman University	Orange, CA	140,000	$130 million	2018
Middle Tennessee State University	Murfreesboro, TN	256,000	$147 million	2014
University of Arizona	Phoenix, AZ	245,000	$136 million	2017
Oregon Health & Science University	Portland, OR	650,000	$295 million	2014
University of North Dakota	Grand Forks, ND	325,000	$124 million	2016
University of Texas at Arlington	Arlington, TX	200,000	$125 million	2018
Texas State University	San Marcos, TX	166,851	$120 million	2018
University of Delaware	Newark, DE	194,000	$132 million	2013
University of Texas at Austin	Austin, TX	140,000	$120 million	2013
University of Massachusetts at Amherst	Amherst, MA	157,000	$114.5 million	2009
University of Chicago	Chicago, IL	400,000	$200 million	2006
Ohio State University	Columbus, OH	237,000	$162 million	2015
Boston University	Boston, MA	170,000	$150 million	2017
University of Washington	Seattle, WA	187,000	$160 million	2018
UCLA	Los Angeles, CA	150,000	$130 million	2017
University of Kentucky	Lexington, KY	263,000	$112 million	2016
Brandeis University	Waltham, MA	195,000	$154 million	2009
Amherst College	Amherst, MA	230,000	$217 million	2018

Source: EYP research. List includes both EYP and non-EYP designed buildings.

/ Rethinking the STEM Building

The most successful colleges and universities we know with new STEM buildings have not merely built new buildings, they've rethought them from the ground up. These institutions have radically redesigned them – either building entirely new structures or dramatically renovating existing ones – in ways that have improved professors' teaching and students' learning processes. The impacts, which EYP has tracked during the last 10 years and chronicled in our formal research studies, have been eye-opening in four dimensions:

- Increasing student enrollment, retention, and interest in STEM majors
- Attracting new faculty to campus
- Creating better places to teach, and thus enhancing teaching
- Creating better places for students to learn and prepare for a post-college working environment that emphasizes team collaboration and interdisciplinary research

For example, a new science center that opened in 2010 at the College of the Holy Cross appears to have helped more than double its number of students majoring in chemistry, although changes in chemistry major requirements also may have played a strong role.[32] What's more, early results show that the center has helped the college attract and retain STEM professors. In the three years after the center opened, Holy Cross increased the percentage of first-choice candidates hired to 78% from 59% (2001-08), EYP research shows.[33] And 82% of STEM faculty say they conduct research faster and more efficiently, according to EYP's study.[34]

At Hamilton College in Clinton, New York, which has 1,850 students, applications for admission rose by nearly 500 a year on average after it opened its new science center in 2005, EYP research shows. While several factors may have contributed to the increase, EYP's research study suggests that the new Taylor Science Center had a large effect. It also appears to have helped increase enrollment in first-level science and math courses by an average of 150 students and boost the number of STEM graduates by more than 40 per year, according to EYP's research study.[35] Additionally, since Hamilton opened its new science center, the number of science majors increased 60% from 2005 to 2014, or from 125 to 200. The percentage of Hamilton students majoring in the sciences rose from 30% to 40%.[36]

Since the center's opening, the number of science majors at Hamilton increased **60% between 2005 and 2014.**

But is this increase significant? Did more U.S. students pursue STEM degrees in that period? In fact, Hamilton outperformed the national increase in STEM degrees awarded. The college increased its number of science and math majors 31% between the time periods of 1999-2006 and 2007-2014, with a relatively constant number of overall degrees conferred. (Hamilton's graduating class of 2008, which had access to the new science building as freshmen, was the first one to show the full impact of the new science center.) Data from the National Center for Educational Statistics on bachelor's degrees conferred at all U.S. degree-granting institutions indicates a 33% increase in degrees in the natural sciences and mathematics between 2005-06 and 2011-12. However, at least half that gain was due to an increase in total degrees conferred. That means Hamilton's increase in STEM majors (with a relatively steady number of total degrees conferred) exceeds the national trend almost twofold.[37] The new science center played a part in this increase.

As those results indicate, these colleges and universities have begun making their STEM facilities a magnet for students and professors. How did they do it? They did so by redesigning existing facilities or building new ones that incorporate these five design elements – all radically different from those that have shaped these campus buildings over the last century:

1. Numerous and strategically placed "soft spaces" that spur informal learning, productive collaboration, and chance encounters for both students and faculty
2. Flexible laboratory spaces that promote hands-on/active learning methods in which students can discover, digest and apply information (not just be lectured to), and which can adjust to the size of group
3. Reconfigurable classroom spaces where professors can move furniture, create workgroups on the fly, and interact rather than just lecture
4. Glass walls that put science and engineering on display and instill a heightened sense of community and collaboration
5. Innovative research labs that promote safe but efficient research and leading-edge research approaches

In the following section, we examine each of the five practices, illustrating them with examples from our work with colleges and universities across the U.S.

/ The Five Hallmarks of STEM Buildings that are Transforming Campuses

Let's explore in greater depth each of the five core design elements of highly effective college STEM buildings. We explain why each one is important to teaching and learning as well as attracting students, professors, and (potentially) research funding. Then we illustrate the impact of each design principle at colleges and universities that have used them in their new or renovated STEM buildings.

1. Soft spaces that create vibrant places for impromptu (but important) conversations

In the field of architecture, "soft spaces" refer to the more informal spaces – such as lounges, alcoves and study areas – where discussions, learning and socializing can continue outside the classroom and the lab. If such soft spaces didn't grace your college's undergraduate science and engineering buildings, you're not alone. Buildings designed in the 1950s to 1970s left out or minimized the number and size of soft spaces. The impact: decades of professors and students with almost no places to interact with one another outside the classroom, professor's office or lab, which in turn meant few opportunities for anything but short, scheduled meetings.

For students, the college years are a prime time for discovery and relationship development. The right soft spaces in campus buildings can help students continue their learning of complex topics in science, engineering, technology, and other STEM curricula outside the lab and classroom. These spaces must offer students and teachers convenient places to interact with one another – that is, next door or in close proximity to classrooms and labs – not floors or buildings away from where coursework is taught. Soft spaces such as study and lounge areas greatly increase the likelihood that students in the same major can find and help one another outside class. There's far less chance of running into others in your major at the main campus library or student union building.

College of the Holy Cross
Integrated Science Complex
Before & After

At the University of New Hampshire's 1960s-era Parsons Hall science building, students were so desperate for soft spaces that they carved one out: a small table under a fire exit stairway. A cramped spot (and cold in the winter), it was the only "soft space" in the building. (The science center has since been rebuilt with additional soft spaces.)

College students place high value on places to socialize not only in academic buildings but also residential structures, according to University of Michigan research.[38] Students with more social soft spaces report higher satisfaction, sense of safety, and engagement with other students on coursework. All of these factors have been found to increase student retention.

Without appealing and useful soft spaces in a STEM building, students and professors have far less incentive to remain in the building after classes or lab work are done. As Hamilton College Neuroscience Program Director Doug Weldon puts it, "There's nothing to keep them there." This is a major lost opportunity for student/faculty interaction. Students don't randomly bump into faculty, which limits further discussion of class material, teaching follow-up, and mentoring. Director Weldon refers to STEM buildings with well-designed soft spaces as a "quality of life" improvement for student/professor interactions, and cites this as one of the most significant benefits of his college's science center revamp. Students display similar enthusiasm for the benefits. Some 75% of Hamilton and Holy Cross students surveyed describe their new STEM facility as either a good place or their favorite place to study, according to EYP research.[39] And we found that more than 50% of non-science majors surveyed visited the complex at least two to three times a week.[40]

Without soft spaces, faculty are less likely to spontaneously interact with each other to share ideas and solve problems as a group. At Holy Cross, before it opened its new science center in 2010, the only place chemistry faculty bumped into one another was in the faculty lounge at lunch, says Bianca Sculimbrene, Associate Professor of Chemistry. Even then, few professors made the trip down the hall. Professors from other science departments rarely visited the lounge. By comparison, after the new science center openings at Holy Cross and Hamilton, 80% of faculty reported interacting with a faculty colleague from another department, EYP research shows.

Getting the most out of soft spaces in a STEM building requires designing the right types for the right situations. In other words, they must go well beyond a lounge with a few couches. The most successful STEM buildings use five types of soft spaces – all of them, not just a few.

First, **large-scale soft spaces** such as atriums are the most prominent and most requested type of soft space. Atriums and commons areas must be both attractive and highly functional for students and faculty. Given that the typical atrium costs around $1 million, the space must entice students to "come inside and stay inside" the STEM center, as Holy Cross administrators articulate their goal.

Five ingredients add up to a productive atrium or commons area, according to student and faculty surveys. It all starts with food: Students stay after class more often if a café or food outlet is there. Also, food attracts non-STEM students to the building, and gets professors out of their offices and chatting with students and colleagues. The other four ingredients are comfortable furniture conducive to working alone or in small groups, tables for projects, quiet, and natural light (thus the value of skylights and large windows).

For example, Trinity University incorporated an atrium for a new science center combining three science buildings. The natural light-filled atrium has tables for groups of up to four, armchairs with smaller tables, sofas and a café. Balconies with soft seating overlook the new atrium.

Trinity University
Center for the Sciences and Innovation

The second key type of soft space is **student study space**. These areas typically accommodate two to eight students with tables and chairs for group study. They're often located next to a larger atrium or commons area, with visibility between both. Hamilton College's Taylor Science Center uses small open balconies overhanging the atrium. At Assumption College, glassed-in spaces in the corners of a two-story loft overlooking the commons proved popular.

How widely do students use these spaces? At Hamilton and Holy Cross, 93% of science majors and 80% of non-science majors surveyed reported using informal learning spaces in the new science centers for studying, either alone or with others, according to EYP research.[41]

The third kind of soft space is the **departmental or discipline lounge.** It serves a less prominent but useful role, giving faculty a spot with a door that closes for privacy during faculty discussions. More institutions are requesting these lounges to serve multiple departments, not just one.

A fourth, and more popular, type of soft space is the **faculty/student "breakout" space**. Located adjacent to faculty offices, such spaces are often walled by glass to make their activity open for all to see. They accommodate on-the-fly meetings between students and faculty, especially for a professor to meet with a small group of students. Faculty members share these areas as well. The spaces also provide a buffer to hall traffic, allowing professors to keep their office doors open without getting distracted by hallway noise and traffic.

For example, at Holy Cross and Wheaton College (in Norton, Massachusetts), soft spaces include small group workrooms and lounges where students and faculty can work together. Walk through the halls at Holy Cross's science center and you will see mathematics professors interacting with students in these spaces. (As an added benefit, faculty/student breakout offices at those schools also function as mini-classrooms for a professor and several students for impromptu discussions.)

Trinity University
Student study space

College of the Holy Cross
Department study lounge

Trinity University
Breakout study space

Finally, **write-up space** in research labs matters greatly to STEM faculty and students. Traditionally (in the 1950s model), universities placed a write-up desk for doing paperwork in the back of a lab, for use by one faculty member. Today's write-up space often spans more labs and serves more people. For example, New York University uses glass-enclosed write-up space located between biology labs in its School of Nursing, School of Dentistry and Bioengineering Institute. Professors share the write-up spaces at Holy Cross's STEM building, and those spaces have windows that look into the research labs. These spaces invite faculty and students to pop in and collaborate. In addition, they become a base camp for students working in the lab – a home in which to keep their food, drinks and back packs. As a result, they make the lab safer.

How a college arranges these soft spaces in its STEM building also determines its success; it's like placing pieces of a puzzle. For example, 73% of Holy Cross students surveyed said informal learning spaces had to be convenient to classrooms and labs.[42] As a result, breakout space must be close to the classroom or en route to an important place that students visit frequently, such as a café.

Outside the university setting, research organizations such as the Arizona Biomedical Collaborative are following a similar design strategy, placing soft spaces like lunch tables and lounges just outside labs, to encourage scientists to sit down together in a convenient spot.

Just how much space does a STEM building need for soft learning? An average of 15% of the square footage in interdisciplinary science buildings should be allocated for informal learning spaces, according to EYP research. These spaces account for an average of 5.4% of the total building cost, at $172 per square foot vs. $355 per square foot overall.[43]

University of Scranton
Loyola Science Center
Lab with adjacent write-up area

2. Laboratory spaces that expose students to multiple learning opportunities

At various times, professors need to address a large group, gather a small group around a lab table, assemble students for multimedia instruction, and conduct different types of experiments. Lab spaces should facilitate these varied modes of teaching.

Holy Cross teaches undergraduate chemistry using what it calls the "discovery chemistry" program.[44] It puts lab work front and center and drives the curriculum and teaching. The school's modernized STEM building (called the Holy Cross Integrated Science Complex) makes it easier to pursue that philosophy, Holy Cross professors say, with labs that accommodate various sizes of student groups and different types of experiments.

The new chemistry classrooms and labs promote better teaching, says Holy Cross Chemistry Associate Professor Sculimbrene. Her organic chemistry lab, which features glass walls and glass hoods, gives her a central line of sight to students as she instructs. Before that, the lab was a dark collection of segregated spaces, and students strained to see and hear her. That gives her opportunities to teach lab sessions in new ways. At Holy Cross and Hamilton, more than 50% of faculty said they changed their pedagogy as a result of the new science centers, according to EYP research.[45] And more than 90% of faculty described their new science building as an excellent learning environment.

Holy Cross also ensures that its buildings and labs support later hours, so students have flexibility to fit more learning into their schedules.

College of the Holy Cross
Integrated Science Complex
Before & After

3. Reconfigurable, flexible classroom space

The cavernous, sloped lecture halls or chairs with flip-up desks of the not-so-distant past do not give professors the ability to teach in ways that require students to do more than just listen and take notes. A professor may want to move classroom furniture around to create a more intimate setting, give a presentation or ask students to work in small groups. Classroom space that can adjust to these needs is important. For example, in Holy Cross science classrooms, student tables are arranged in tiers; each tier holds two sets of tables and chairs that swivel, so students can face forward for lecture or swivel the chairs around to do group work with students at the other table. Our research at Holy Cross and Hamilton found that almost 50% of their instructors introduced new lab exercises or assignments in an existing course as a result of their science centers' more flexible classrooms.[46]

Additionally, since the size of student groups vary from class to class, classrooms must be able to adjust. Professors may need to run multiple sections from a lab, depending on class size. Prep rooms for experiments should also be laid out in a way that accommodates multiple sections of students, if needed.

Flow also matters: Students need to move in and out of prep rooms and between classroom and lab work smoothly and safely. For example, Holy Cross students move between these spaces carrying delicate equipment and chemicals without entering a hallway filled with the general public.

Acoustics make a difference in classrooms and labs, for safety and learning reasons. Professors need students to hear well in large and small groups. While many institutions winnow out acoustical improvements during the budgeting process, Holy Cross professors praise the safety and educational value of quiet classrooms and labs, compared to the school's previous science buildings, which suffered from noisy air circulation and vibrated when trucks drove by the buildings.

Trinity University
Center for the Sciences and Innovation

4. Glass walls that make teaching and research visible

Glass walls represent the complete opposite of the traditional opaque, cinder-block walls in STEM buildings of the past. At first glance, a glass-filled science and engineering building may appear to be more about form than function. However, in our experience, glass walls do much more than provide an attractive environment.

First, glass walls in labs and classrooms put science and engineering on display, to STEM and non-STEM major students, maintaining and even sparking interest in science, engineering, and mathematics disciplines. More than 50% of the Holy Cross students we surveyed who visit the science center said being able to see into labs from their glass walls inspired them to learn more about science.[47] This represents a core goal for any university strengthening its STEM program. What's more, in older STEM buildings, opaque walls don't help professors learn what colleagues are working on. These walls don't spark a sharing of ideas, or encourage problem-solving among faculty and/or students. Glass walls do, says Professor Sculimbrene of Holy Cross. "When spaces open up, it gets people talking," she says. Almost 75% of faculty surveyed at Hamilton and Holy Cross agree that "glass walls in the science facility create a stimulating place to work," according to EYP research.[48]

Another benefit: Having to explain and discuss your visible research with other people delivers a useful form of learning. At MIT's Broad Institute, a group of cancer researchers meets regularly with the public to explain their research projects, for this reason, among others.

Late at night, students also feel safer working in labs with glass walls, instead of behind closed doors, professors say. Indeed, at Hamilton College, nearly every classroom and lab space is visible to anyone walking by, says Director Weldon. Beyond safety, it creates a sense of energy and vitality, faculty report.

Wheaton College
Mars Center for Science and Technology

5. Research labs that facilitate efficient, safe research, and better ways of teaching

In the remodeled research labs of Hamilton and Holy Cross, numerous advantages have emerged for faculty and students.

First, students reap efficiency and safety benefits when lab design prioritizes ease of reaching instruments and reproducing experiments. Easily shareable lab space also encourages collaboration. For example, at Hamilton College, where all STEM seniors do a research project, professors often guide students to projects that dovetail with their own research interests, offering a greater chance for collaboration, Hamilton's Neuroscience Director Weldon says.

At Holy Cross, faculty research labs share a connecting interior corridor, with open doors between them. Professors stay well aware of what colleagues are pursuing at any given time and can assist one another if desired. From our research on the impact of the science buildings at Holy Cross and Hamilton, we found that more than 62% of faculty believe it is easier to collaborate with other faculty in the newly designed labs.[49] Additionally, almost 50% of faculty reported that their research output is greater in the new labs.[50]

Hamilton found its new science center helped it conduct more research in one program. The new STEM building has been a key factor in increasing the number of students who participate in its summer science research program. Between 2003 (two years before the new building opened) and 2006, the number of students in the program increased 43% from 61 to 87. Since 2006, an average of 86 students have been involved in the program; and in 2014 that number rose to 100.

What changed? The new building enabled Hamilton faculty to create more and larger summer research projects. It also enabled them to house more students using better labs and lab equipment. Two Hamilton scientists who have been at the college since the 1990s said the new STEM building had a big impact on the growth of the summer research program. The old labs were cramped, dingy and hot in the summer, and research work often spilled out into the hallways. The faculty members also said the new building helped attract more students to Hamilton who were interested in conducting scientific research.

College of the Holy Cross
Intergrated Science Complex

/ Three Core Benefits of Designing STEM Buildings This Way

So how do these five core design principles strengthen college STEM programs? We and the schools we have worked with on more than 20 such projects have seen three main benefits:

1. Higher levels of student enrollment and retention.

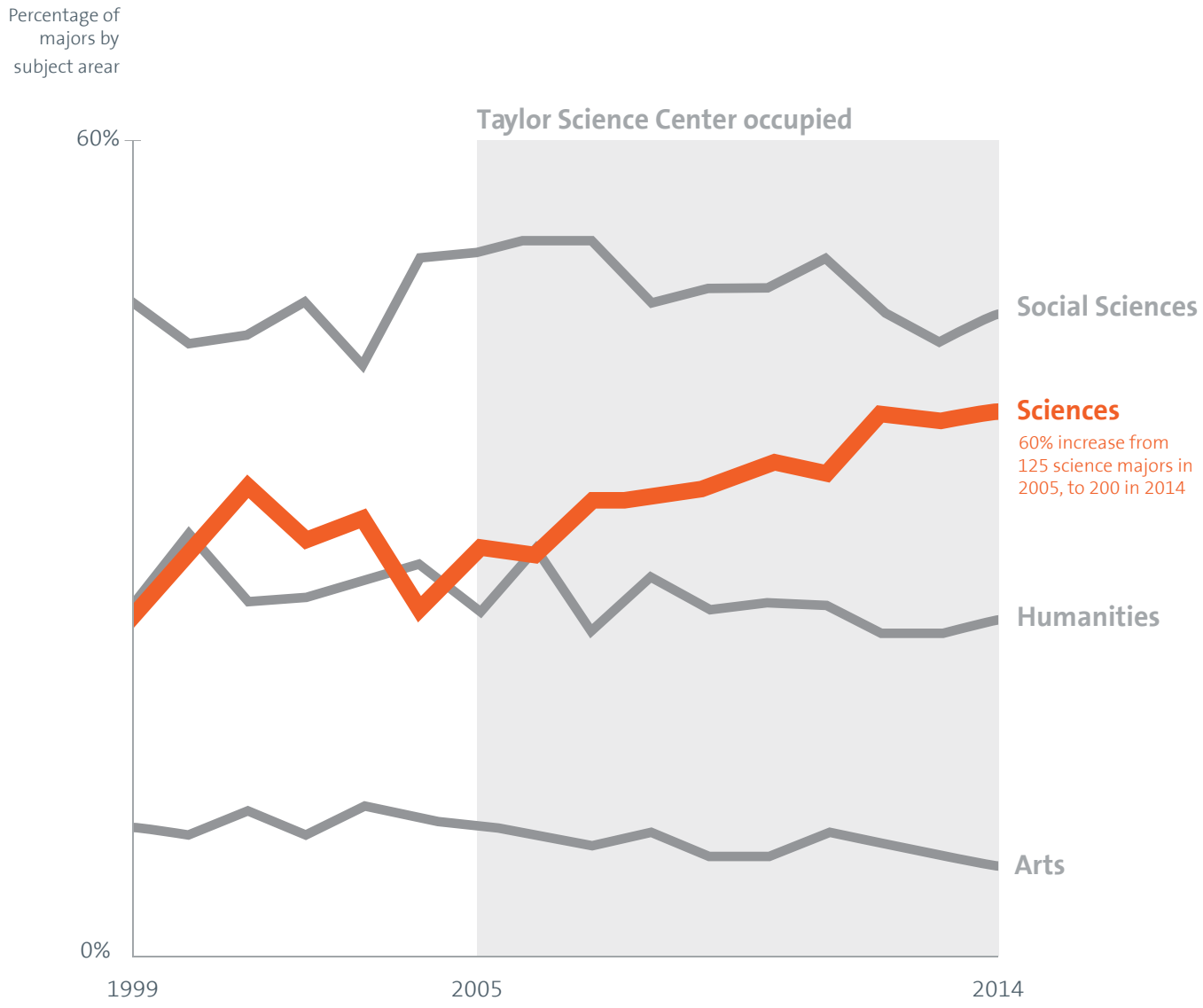
Buildings designed this way have helped attract and retain more STEM students. And because of the high defection rate of STEM majors, retention is critical. (A 2010-11 study of 1,669 U.S. colleges and universities found they lost $16 billion in revenue to student attrition across all majors.[51]) Most institutions that designed their STEM buildings in the ways described here report that the science buildings have changed from a campus tour eyesore to a tour highlight. Holy Cross executives said campus tours used to stop outside the science buildings, but not go in. Now, the tours use the science center as a showcase of Holy Cross' commitment to faculty/student interaction and undergraduate research, says Charles Weiss, Director of the Office of Strategic Initiatives and Associate Professor of Psychology.

At Hamilton College, the new science center appears to have helped boost applications for admission by an average of more than 500 per year since the opening. In addition, the percentage of students enrolled in first-level science and math courses has been increasing ever since the college opened the new science center, from about 25% in 2003-2005, to 30% in 2013-2014.

That number of students exploring first-level science and math classes is important at Hamilton, since its freshmen don't initially declare a major. Thus, they "shop" many classes before deciding whether to pursue a STEM major. Looking closer at the EYP research data using average values, we found enrollment in Hamilton's 100-level science courses was about 1,400 students in 2000-01, and between 1,300 and 1,400 from 2001-02 to 2005-06. Beginning in 2006-07, enrollment topped 1,500 – a sizable increase in enrollment, one year after the opening of the TSC.[52]

In addition, Hamilton's percentage of graduating students majoring in the sciences has risen steadily, from 30% in 2006, to 40% by 2014. While that may be due to other factors besides the new science center, our research suggests the center has played a role.[53] By creating a destination building where all students want to visit, colleges and universities expose students who may be undecided about majoring in science to the possibilities. Using glass-walled rooms and labs, institutions keep STEM students engaged and attract interest from others. Student surveys at Wheaton, Holy Cross and Trinity have found the new science centers have inspired the majority of students to learn more about science and engineering.

AT HAMILTON, ONLY STEM MAJORS INCREASED AS A PERCENTAGE OF ALL MAJORS BETWEEN 2005 AND 2014

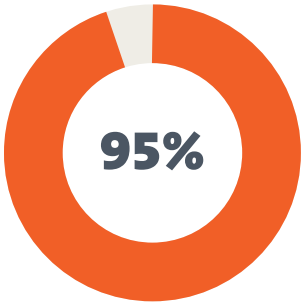


Source: EYP research. Sum of percentages exceeds 100 because of double majors.

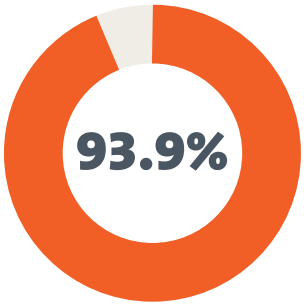
2. Better teaching, and better places to teach.

Satisfied professors are more likely to stay put, and enthusiastic professors welcome the chance to innovate with coursework. At Wheaton, more than half of the 20 faculty members surveyed who had taught in the old and new buildings changed the way they teach; at Holy Cross, half of the 12 faculty members surveyed altered their teaching approaches, according to research we have conducted.[54] This includes adding new assignments and/or lab exercises. At Holy Cross, more than 80% of faculty reported that they can carry out research more quickly and efficiently in their new labs. More than 80% of faculty also found it easier to collaborate with other faculty in the new labs. Thanks to a larger wet lab for neuroscience at Hamilton, Doug Weldon can do new projects with undergraduates. "We can bring students in from lower level courses to do brain dissections for a day," he says. "That opportunity wasn't there in the old building."

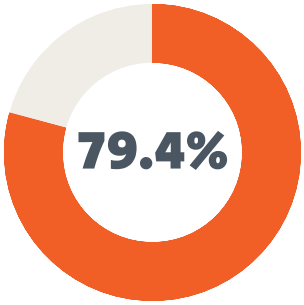
HOW HOLY CROSS FACULTY RATE THE NEW STEM BUILDING



% of faculty who are moderately, very or extremely satisfied with the new/renovated complex



% of faculty who rate the overall quality of the teaching environment as very good or excellent



% of faculty who praise the new/ renovated facility's flexibility in accomodating different teaching strategies or styles

Source: EYP research

3. Improved student learning and preparation for the professional world.

Third-party research shows that group problem solving improves STEM learning at the college level. "For example, teachers can pose a question and encourage students to work together in groups to come up with a consensus response," said a brief funded by the National Science Foundation. This allows for on-the-spot reasoning and discussion, and, moreover, allows students to test their own understanding. So does peer instruction where students teach each other concepts.[55] Soft spaces and flexible classroom and lab spaces help professors use these approaches with students.

In the professional world, an increasing number of companies design their research spaces in a similar way. Soft spaces and design elements that encourage spontaneous interaction benefit workers in companies seeking better communication, according to research by MIT Professor Alex "Sandy" Pentland.[56] He identified three key elements of successful communication: exploration (talking with people from outside your immediate team to identify knowledge and ideas), engagement (talking to many people inside your immediate team), and energy (as measured by the number and nature of exchanges with people on your team). Spaces, such as break areas or eating areas with long dining tables, can encourage exploration and engagement among team members, Pentland notes.

Accordingly, leading technology companies and research organizations design buildings with plenty of soft space, to encourage information sharing and collaboration among STEM professionals. For example, the new Shell Research & Technology Centre Amsterdam (SRTCA) utilizes many common spaces, labs for multiple teams, "meeting zones," and cafes, connected by a glass-filled atrium. Shell's goal: "collaboration and the exchange of ideas among its scientists," says HP Calis, manager of the building.[57] In another example, the Francis Crick Institute, a multidisciplinary biomedical research institute, plans to open a new lab in London in early 2016.[58] The building design, for 1,300 scientists, features glass-walled labs and a vast common atrium. Each lab will have space for about 10 investigators. Instead of cubes, the scientists will have write-up areas next to their labs – much as faculty and students do at Holy Cross and Hamilton. Samsung's new open plan headquarters in San Jose aspires to be a "womb for innovation – insanely rapid innovation," *Fast Company* reported.[59] Design features include an open floor plan, many soft spaces where people from different departments can interact, walls of windows, and natural light. Google also builds campuses "designed to maximize chance encounters."[60]

New York University
Silver Building Research Laboratory

Barriers to Building Innovative STEM Buildings, and How to Overcome Them

The five principles we explored in the previous section are a radical departure from the way most college STEM buildings have been designed within the last 100 years. As a result, college and university executives who pursue STEM building projects of this type should expect to face a number of barriers. From our experience and the experience of our clients, **three stand out**: faculty skepticism about the impact of building design on learning, worries about campus aesthetics, and cost. Let's look at each one.

Faculty Skepticism

It's natural for faculty to question the science and engineering building design principles discussed in this article. Before they see a new science center in operation, many professors haven't made the connection between building design and quality of teaching and learning. The idea that a STEM building can help faculty enhance teaching quality is a new concept for them – and as such, it has a learning curve. Also, many of these faculty are highly accomplished, dedicated teachers, who have made the best of aging facilities for quite some time. Starved for space, some of them may want to stick with their current classroom and lab designs in any new buildings, and merely add space. (This is understandable given how cramped faculty quarters become in dated buildings.)

But additional space is not necessarily better space. And a piecemeal effort to enlarge classroom and lab space is not likely to boost interactions among faculty and students or transform a STEM program's reputation – as Holy Cross learned.

For decades, before it embarked on its new science center, Holy Cross had simply upgraded aging STEM buildings one at a time. In 1985, it completed a new building (Swords Hall) that upgraded chemistry facilities. The school remodeled a biology building in 1999. But its sporadic upgrades didn't change how students worked with faculty, or improve the reputation of its science programs. By contrast, the college's Integrated Science Complex has become a destination building on campus, one that has attracted more students in both STEM and non-STEM majors.

Holy Cross and Hamilton professors reported real differences in their teaching approaches after the opening of their new science centers, with flexible classrooms and light-filled labs. For example, nearly half of instructors at the two colleges said they introduced new lab exercises or assignments within an existing course, according to EYP research. More than a third of the professors changed the way they run lab sessions with students.[61] (See case study on Holy Cross on page 41.)

At some colleges and universities, not every faculty member believes in the value of interdisciplinary research or will want to share research space. Thus, they may argue against interdisciplinary spaces. For years, chemistry and biology professors on many campuses operated in separate departments and separate buildings. However, interdisciplinary research is now a strong trend not only in academia but also in technology, business, and medical research.

Interdisciplinary research and projects will be a part of many STEM students' professional lives. Preparing students early for this reality makes sense. Even the days of single-author scientific papers have largely vanished, notes Kenneth Mills, Professor of Chemistry at Holy Cross.

With trends such as big data analysis and artificial intelligence driving a need for cross-disciplinary expertise at technology companies, tech giants such as Cisco are pushing universities to emphasize it.[62] Medical research institutions, such as London's Francis Crick Biomedical Research Institute, also prioritize interdisciplinary research, seeking breakthroughs to complex medical questions (cures for cancer and heart disease, to name a few) through work by many breeds of scientists.

Thus, one way to argue for buildings that promote cross-disciplinary interactions is to point to the corporate world. Businesses will be attracted by graduates who have already operated in cross-disciplinary settings. That should be a big selling point for both students and parents. And, like Cisco, an increasing number of large companies will also be attracted to universities that fully promote interdisciplinary research. Colleges and universities that can make a strong case for exactly how their buildings accelerate interdisciplinary research should have a strong point of differentiation when it comes to attracting research grants.

Soft spaces and flexible classroom and lab spaces help professors use group problem-solving teaching methods.

Aesthetics

The second significant barrier is one of appearances and whether a new science building can aesthetically fit within a campus. Universities seeking to upgrade STEM buildings frequently have to deal with an administration's desire to maintain a traditional and unified design aesthetic on the campus. Some university presidents value building appearance above all, insisting all buildings must be Georgian or Gothic, for example. They may worry that a modern building with extensive glass may not fit the profile of college campuses, historic institutions associated more with ivy-covered brick buildings than sleek, modern-looking glass structures. But in our experience, universities can blend in design elements that fit with the campus style, while still following the five design principles mentioned in this article.

Take the example of Hamilton College, an 1,850-student private liberal arts school in upper New York state. The exterior of its new STEM complex has traditional brick elements, including the façade of a 1925 science building, befitting both its position on a historic quadrangle and the overall campus aesthetic. These elements blend with a large amount of glass, leading into a light-filled atrium, and modernized classrooms and labs.

In another example, a renovation of the University of Richmond's 1970s-era Gottwald Science Center included a new entrance that reflects the campus Gothic design. Inside, design elements such as arches also nod to the Gothic style.

Hamilton College
Taylor Science Center
Before & After

Cost

This is the third big barrier to STEM facility upgrades designed along the lines mentioned in this article, and a significant one for all colleges and universities. We typically see a 125% to 200% cost increase for new construction compared to renovation.

Often institutions can't afford the ideal approach of starting from scratch with an entirely new building. As a result, many colleges and universities retrofit existing buildings, typically combining or connecting them in new ways.[63] Consider the University of Richmond. When it modernized the Gottwald Science Center, it connected existing buildings, which made the project affordable. The design renovated the classrooms and labs of four existing science departments, replaced a science library with a new atrium connecting those departments, added faculty offices and installed a new entrance. The 2003 project cost $34 million, an estimated $17 million less than the cost of an entirely new building.

Unless they've visited a campus that has completed an ambitious renovation project, some faculty and administrators may struggle to envision how such a remodel could breathe new life into old buildings. But examples like the University of Richmond show the viability of the approach.

When entirely new buildings are needed, many colleges and universities have made it possible by looking for outside money rather than trying to raise the entire amount through bond offerings or tuition increases. In fact, many institutions have sought private donations for a large chunk of the cost of their STEM buildings. At the University of Vermont, about a quarter of the cost of a new $104 million STEM complex, (scheduled to open in 2018), will come from donations.[64] The University of Mississippi raised more than $53 million as of September 2015 for a proposed $135 million science building, with donations from the Gertrude C. Ford Foundation and others.

Similarly, Holy Cross raised significant money to fund its new science complex. Walk through the Integrated Science Complex, and the college makes clear that alumni support helped build this facility: Many classrooms, labs and related spaces bear a donor's name, identified by a plaque outside the door.

The percentage of square footage devoted to soft spaces in college STEM buildings has risen from less than **5% in the 1990s to 15% today.**

Why Redesigning STEM Buildings Will Become Only More Important

STEM programs have become vital assets to many colleges and universities, large and small. U.S. corporations' appetite for high-quality STEM graduates is becoming even more voracious. Colleges and universities that can supply those students – and attract prestigious professors who can teach them and conduct valuable research – will gain a significant edge.

However, students, parents and faculty expect much more from undergraduate STEM education than was the case as recently as the 1990s, and they enjoy a broad range of college choices. From our research and experience, colleges and universities that bring STEM buildings up to date using the five aforementioned core design principles find their buildings key to bolstering their STEM program's reputation and attracting students. And in the first two years after Holy Cross opened its new science center, the facility appears to have helped significantly increase acceptance rates of first-choice faculty hires, although the sample size is too small to establish a firm connection.

As discussed earlier, leading corporations and research institutions today design buildings using similar principles. Now is the moment for colleges and universities to catch up – to invest in collaborative spaces that encourage heavy interactions among students and faculty across disciplines. The future employers of STEM graduates already believe that the right buildings attract the best people and improve the product and have invested heavily in creating them.

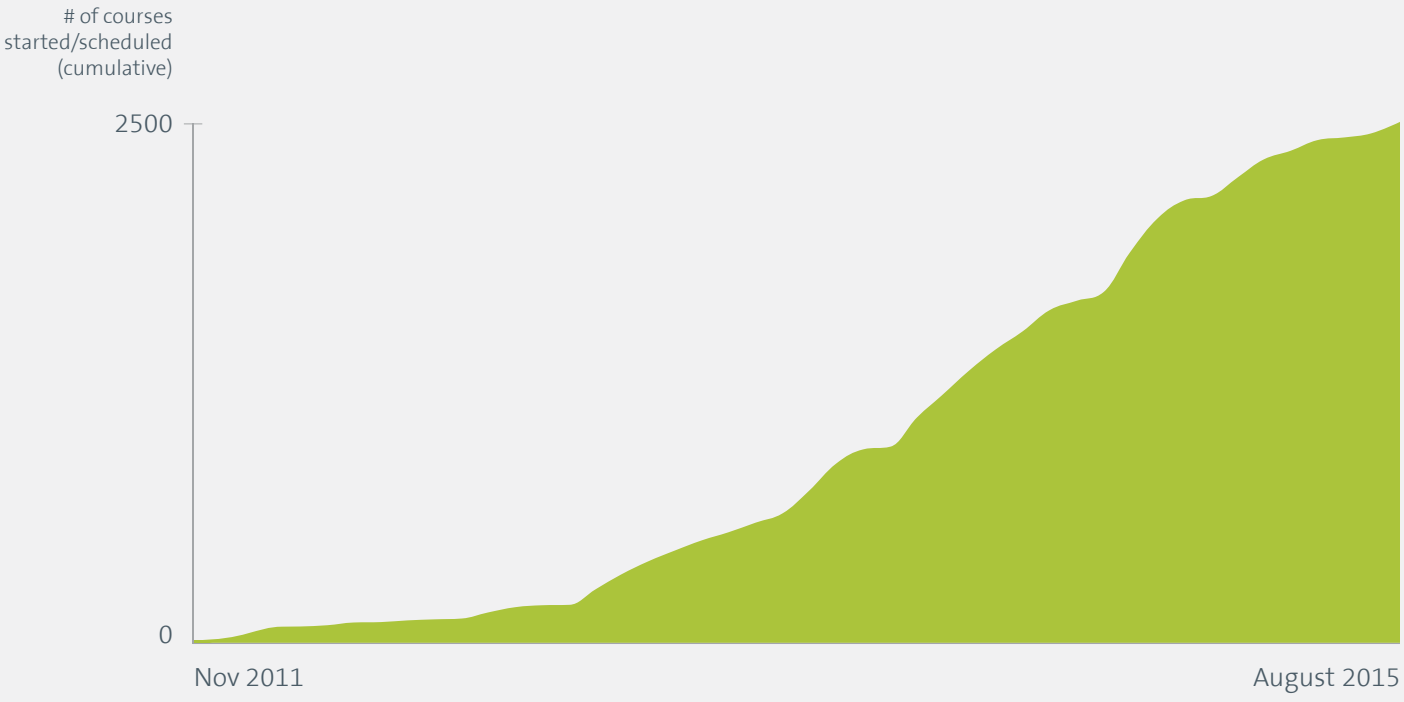
When we consider the trends in how education is delivered, the value of redesigning the college STEM building makes even more sense. Just as online services have been reshaping the bricks-and-mortar environments of retailing, media, sports, and other sectors, they are giving potential students more ways to get a degree beyond attending a four-year bricks-and-mortar institution. Colleges and universities would be shortsighted to ignore the potential impact of online education.

If you believe that massive open online courses (so-called MOOCs) will soon become a way many people earn their degrees, a college that wants to attract students will have to deliver a campus learning experience that can't be replicated in the online world.

Better buildings – designed much differently than the STEM buildings of the last 100 years – have boosted colleges' and universities' appeal to students, parents, future employers, and potential research benefactors in both tangible and intangible ways. They replaced formerly sequestered labs with flexible, integrated spaces that foster collaboration among different science disciplines and allow professors to use 21st-century teaching methods. The right spaces have made it easier for formerly lab-bound students to solve problems together, making them more marketable to future employers who value collaborative skills. They've made science and engineering more approachable and exciting than the staid buildings of the past did, attracting today's amenity-conscious students and their parents. Major investments in STEM buildings also have signaled to research funding sources that the college is serious about its science and engineering programs.

Institutions that see the need to update STEM facilities using core design principles laid out in this article can learn significant lessons from colleges and universities that have recently made this journey. It is not uncharted territory. Given the typical length of this journey – including securing administration approval, planning fundraising, and aligning the needs of administrators, faculty, and students – institutions that understand the need for a modernized STEM complex should act sooner rather than later.

MORE THAN 2,400 MASSIVELY OPEN ONLINE COURSES (MOOCs) WERE OFFERED AT UNIVERSITIES ACROSS THE COUNTRY BY SUMMER 2015, **UP FROM JUST 3 IN 2011.**



Source: Class Central

/ Case studies

Hamilton College:

How a New Science Building Boosted Enrollment and Helped Fuse Research with Teaching

Hamilton College believes in the educational power of research work and collaborative learning for undergraduate STEM majors. By the late 1990s, the way the Clinton, New York, school taught science had changed accordingly. But the facilities had not, says Doug Weldon, director of Hamilton's Neuroscience Program.

"Research in general had been incorporated much more into our teaching style," Director Weldon says. But inadequate and outdated lab space made this challenging. For example, geoscience professors decided to do away with the difference between lecture and lab meetings, combining both elements into one class period. "The faculty had to sacrifice some of their research space to allow that kind of teaching to take place," said Director Weldon.

Hamilton's dated science buildings also had physical issues such as leaks and safety concerns such as old hoods in labs. The situation created problems since Hamilton required a senior project for all of its students, which meant its STEM majors were doing empirical research independently, and competing for scarce lab space. Moreover, remodeling the science center was a way to attract a high caliber of science students, enhancing the quality of the overall student body.

So the trustees approved a new STEM center, the Taylor Science Center (TSC), the college's largest-ever construction project. Completed in September 2005, the project completely renovated one building, demolished a second and built a new multi-story wing and two-story atrium connecting the renovated and existing buildings. The project increased the STEM department space, including shared space, by more than 50%.

Initially, the TSC housed offices and labs in six departments: archaeology, biology, chemistry, geology, physics, and psychology. Later, the center converted space to add two computer science classrooms and offices for computer science faculty. The chemistry department had previously been in its own building down the street. During the upstate New York winters, that cold trek did not encourage collaboration with other faculty. "Having everyone under one roof really has opened up opportunities for collaboration between chemistry and other departments, particularly biology," said Director Weldon.

Hamilton College
Taylor Science Center
Before & After

Hamilton College
Taylor Science Center

Design-wise, the college incorporated glass extensively in the modernized building to stimulate interest in the sciences. Nearly every classroom and lab space is visible when walking through the building. However, the TSC's exterior design retains traditional elements and preserves the façade of the 1925 science building, a nod to its location on a historic campus quadrangle.

EYP improved classroom and lab spaces while adding informal spaces where faculty and students can meet. The building's centerpiece, the southern atrium, has made it a campus favorite for studying and events, Director Weldon says. Humanities professors, for example, frequently use the building for talks.

The TSC made a measurable impact on STEM enrollment as well. Applications for admission have increased by an average of more than 500 per year since the opening. Enrollment in 100-level (introductory) science and math courses increased by an average of 150 students. Finally, the number of graduates majoring in the sciences and math increased by an average of nearly 42 students since construction.

For example, the Neuroscience student group has nearly doubled in size since the TSC opened, from an average of 8.1 from 1999-2006, to 14.5 from 2007-2014. The Neuroscience class of 2016 has 26 seniors set to graduate, said Director Weldon.

As the college hoped, the quality of STEM students arriving at Hamilton has risen since the building of the TSC. "Admissions is able to attract good science students," Director Weldon says. "The quality of Hamilton students is substantially more impressive than 10 to 15 years ago," he adds. He cites three other contributing factors related to that improvement, starting with the college's switch to optional SAT scores and rollout of an open curriculum (wherein students have requirements within a major, but not university-wide core class requirements). Third, since opening the TSC, Hamilton committed to additional construction, including social sciences and arts buildings, applying lessons from the science building.

Hamilton has won several STEM grants since the TSC opening, allowing for new chemistry equipment and a new professor. "The foundations understood that Hamilton was making big investments and the space was available to make that equipment be used effectively," said Director Weldon.

Teaching and research have changed as well. In one example, a new computational chemistry lab accommodates 20 students and computers, far more than its predecessor. Thanks to a larger wet lab for neuroscience, Weldon can do new projects with undergraduates. "We can bring students in from lower level courses to do brain dissections for a day," he says. "That opportunity wasn't there in the old building."

Movable furniture in classrooms gives faculty flexibility for small group learning and collaborative projects. "A lot of what we do in my department has students engaging in experiences in groups," Director Weldon said. "In addition," he added, "the new facility created significant quality of life improvements, such as increased faculty/student interaction."

The TSC fosters "a real sense of community," Director Weldon says. "We get faculty and students coming in to have lunch and coffee in the atrium. Those quality of life changes are night and day for us. There are impromptu questions and issues that come up, and advising that comes up. Those are the intangibles that are particularly meaningful."

College of the Holy Cross:
How a New Science Center Has Invigorated Campus

Back in the late 1990s, Holy Cross had an eye-opening moment about the nature of its science buildings. A research foundation president came to the college for a site visit in advance of what the faculty and administration expected would be a very significant grant. And while the foundation president knew of the college's excellent record of producing leaders in science, he was surprised by the state of the physical plant in STEM disciplines. The rest of the story is both good and bad. While Holy Cross did not receive the foundation grant, that visit galvanized the college to invest in science facilities, resulting in an Integrated Science Complex.

The private liberal arts college has 2,885 undergraduates, with STEM majors that include chemistry, biology, physics, mathematics, and computer science. Its science programs stress guided inquiry through lab work. The school's "Discovery Chemistry" program puts lab work at the center of the introductory undergraduate classes as does its introductory physics class.[65] In Discovery Chemistry, students collect data in the lab, pool it with their fellow students, and use the data to discover chemical concepts in the classroom, with the direction of the professor. This allows students, from their first days at Holy Cross, to learn in the same way experimental scientists do.

Since the 1970s, Holy Cross had pursued a piecemeal approach to updating its older 1950s-era science buildings. Older chemistry labs were upgraded, for example, when a new STEM building was constructed and an existing building was renovated in 1985. The biology building was updated in 1999. But the collection of disparate buildings wasn't helping to foster interdisciplinary research or faculty collaboration. "We had buildings next to each other, but no place to talk," says Charles Weiss, Director of the Office of Strategic Initiatives and Associate Professor of Psychology. Overall, lab space was spread out across buildings, dated, and inadequate for a college where research drove the curriculum.

EYP helped Holy Cross blend one new and four old buildings to create the Integrated Science Complex (ISC), a 270,000-square-foot facility that added new teaching and research spaces for chemistry, physics, and math.

Completed in January 2010, the ISC features classrooms and labs with glass walls and a central atrium with a café, in a space that was previously an unwelcoming atrium between two buildings. Informal social and study spaces link the departments of biology, chemistry, mathematics/computer science, physics, psychology and sociology/ anthropology, plus the science library.

College of the Holy Cross
Integated Science Center
Before & After

"Our students learn science by doing science, by using the scientific method en route to acquiring the facts, theories, and principles of the STEM disciplines," says Professor Weiss. The ISC was designed to support how faculty teach science and conduct research. "The students are thinking like scientists, working collaboratively, as they will in grad school and afterward," says Kenneth Mills, Professor of Chemistry.

For example, in the teaching labs, new pre-lab spaces let students get instruction from a professor before a lab experiment, come out during the lab to ask questions of fellow students or pool data, then re-enter the lab.

Holy Cross chose glass-walled, light-filled classrooms and labs to keep STEM students engaged and attract interest in science. But it's not just about a feeling of excitement.

The new chemistry classrooms and labs are safer and encourage better teaching, says Bianca Sculimbrene, Associate Professor of Chemistry. Her organic chemistry lab with a large open floor plan, glass walls, and glass hoods gives her a central line of sight as she instructs the students; whereas before, the lab was a dark collection of segregated spaces, and students strained to see and hear her. "It's not very conducive to learning when you're searching for daylight," she says, adding that she "wouldn't go back," to the old-style labs. In her new lab, the experiments are better supported, allowing students to work through experimental challenges in pairs. Students can also see connections between various lab setups at one time.

Beyond the teaching benefits, the ISC has become a campus destination, fostering informal meetings between students and faculty. For example, 54% of students surveyed said they go to the ISC to study or work on group projects. Nearly a third (31%) go the ISC is to "hang out with others."[66] STEM and non-STEM students come to the building to eat, study and chat with professors. "Having food there is huge," says Professor Sculimbrene. The survey found 77% of students go there to buy food or drinks. "You run into students at the café." (And as a result, future academic buildings at Holy Cross will include some food service.)

For Holy Cross, attracting and retaining STEM majors was a major goal of the project. To date, the evidence looks promising. Between 2001 and 2011, chemistry averaged 19.3 majors per graduating class, with a high of 25. From 2012 to 2016, the average number of students majoring in chemistry per graduating class more than doubled, to 41.4, with a high of 58 for the 2016 graduating class. However, we must note that curriculum changes may have contributed to this increase as well, according to our study on the impact of the college's Integrated Science Complex.[67]

The joined science quarters have also led to greater faculty interaction. In a recent example, Analytical Chemistry Professor Amber Hupp, struggling with a problem involving a large data set, collaborated with Mathematician Edward Soares. He then looped in Computer Scientist Kevin Walsh. How did the collaboration start? With a chat between Professor Hupps and Edward Soares in the café. Students are now benefiting from the interdisciplinary research project."

We had two students work on the project; one was a research student of mine who double majored in chemistry and math and the second was one that worked for Ed and I in different ways but was strictly a math major interested in applied math," says Professor Hupp. "It's been a great collaboration and is still ongoing. The ISC really allowed for this project to take its current shape."

In another example at Holy Cross, Alo Basu, an Assistant Professor of Psychology, and Shannon Stock, an Assistant Professor of Mathematics, are pursuing an interdisciplinary research project with two Holy Cross undergraduate students. The two assistant professors first met and got to know each other better when teaching in adjoining time slots in the same building. Professor Stock, who has statistics expertise, sought a research scientist's input for a project she was pursuing involving a large, complex data set. An undergraduate student pointed out to her that Professor Basu's background might be a fit for the project. "That's the culture here," Professor Basu says. "Faculty are very accessible and students are very curious about how to get involved in our work. Camaraderie spurs collaboration."

The project, being done in concert with a physician, David Henderson, Chair of Psychiatry at Boston University Medical Center, is exploring how genetics affect patients' risk for side effects from anti-psychotic drugs used to treat schizophrenia. (Work is ongoing as of spring 2016.)

The professors have looped in two Holy Cross sophomores, one a psychology and chemistry double major, and one a math major, who are helping prep a large database of patient data for analysis. The students cemented their spots on the research project over lunch with the professors in the Science Café.

Interdisciplinary research projects like this are on the rise at Holy Cross, says Professor Stock, noting the university recently held a multi-day faculty workshop on how to integrate teaching and research activities across disciplines. "It is being encouraged and students benefit," she says.

College of the Holy Cross
Integrated Science Complex

Professor Basu says she likely would not have felt comfortable jumping into the project, which she is finding quite intellectually stimulating, if she hadn't bumped into Professor Stock often in the ISC.

The ISC building, with its informal spaces and glass walls, has also improved department cohesion, Professor Sculimbrene says. "When spaces open up, it gets people talking."

It's too soon for Holy Cross to definitively determine whether the ISC has helped attract and retain faculty. However, the fact that the percentage of first-choice faculty candidates hired rose from 59% from 2001-08, to 78% from 2010-2012 suggests it had an impact in the first three years after it opened. And for Holy Cross professors such as Sculimbrene, the appeal is clear. "The right kind of space matters when you're choosing where to teach," she says. "It tells you the college values what you're doing. And it helps you see what kind of community you are joining. Do they want the interactions between students and faculty?" There is a difference, she notes, between what a college says about such interactions and where it invests.

Due to the work of professors such as Sculimbrene and Mills, Holy Cross wins research funding that fuels faculty research interests and engages undergraduates in research projects that get published in scientific journals and presented at national meetings. For example, in 2013 Professor Mills won a $567,000 three-year grant from the National Science Foundation to study the chemical mechanism of protein slicing. During the last decade, his research projects, which integrate student research, have enjoyed uninterrupted financial support from the NSF, bringing in more than $1 million.

Trinity University:

A New Science And Engineering Center Unites a Vibrant STEM Community

Trinity University takes pride in undergraduate STEM programs that combine engineering with the traditional sciences and stress research and interdisciplinary projects. However, a decade ago the San Antonio, Texas, school believed its STEM buildings were holding it back. "The old facilities were not welcoming or student-friendly," says David Ribble, a Trinity Professor of Biology. "They were not safe. They were not flexible. And they did not support modern ways of teaching because they were focused on old lecture models."

A new science complex completed in 2014 has changed all of that. Trinity's Center for Sciences and Innovation (CSI) was the biggest construction project in the school's 147-year history. The center has been strongly embraced by faculty and students – with the former giving its new laboratories a good or excellent rating, and the latter making it a frequent destination, even for non-STEM majors. And that's important for a school with a top-notch reputation among private liberal arts institutions for preparing students for advanced degrees in science and engineering.

Trinity rests on an elegant 117-acre hilltop campus that overlooks downtown San Antonio, the nation's seventh-largest city and second biggest in Texas (ahead of Dallas). The NSF lists Trinity among the top 50 private, liberal arts institutions in the country that send graduates on to earn doctorates in science and engineering. Of its 2,100 undergraduates, more than a third (36%) are STEM majors. They and Trinity's faculty make for a vibrant science community.

But for several years leading up to 2010, Trinity's science and engineering faculty was dissatisfied with the school's science and engineering buildings, classrooms and labs, Professor Ribble explains. One big reason: They severely limited professors who wanted to bring new team-based teaching methods into the classroom and lab. This was especially the case for professors who wanted to bring faculty from other disciplines – biology, chemistry, computer science, engineering sciences, math, physics, psychology and geosciences – into the room.

Those departments had been scattered throughout four buildings on the Trinity campus. "We were divided among four separate buildings and this was problematic," said Professor Ribble. The problems of physically separating programs came to a head after the university won a number of teaching and research grants that required cross-disciplinary approaches. "They really made us realize how problematic our facilities were to do science and engineering education in the 21st century."

Trinity University
Center for the Sciences & Innovation
Before & After

Faculty pressed for more flexible classroom and lab space, as well as a building that would unify Trinity's science and engineering programs and become a destination for students and faculty. By 2006, university leadership was convinced they needed a new science center.[68] Phased construction on the CSI building began in June 2010 and was fully completed in the summer of 2014 at a cost of $127 million.[69] (The first new addition opened in spring 2012.) The CSI building linked all science and engineering programs, replacing four separate buildings. The EYP design razed one building, completely renovated another, and added new construction.

The facility – including 80,000 square feet of renovated space and 150,000 square feet of new construction – houses the engineering science, biology, chemistry, computer science and psychology departments, plus the college's Center for Innovation and Entrepreneurship. The entire complex also includes the Geosciences, Physics and Astronomy, and Mathematics departments in Marrs McLean Hall, which was renovated and connected to the CSI building.

The CSI building follows a "science on display" philosophy, with interconnected glass-walled clusters of classrooms, laboratories, offices and social spaces. The school wanted the design to bring science and engineering into the open for all students, bolster student-faculty interaction, and accelerate interdisciplinary research and teaching."

Trinity University
Center for the Sciences & Innovation

The new facilities have allowed faculty to teach in new, exciting ways," says Professor Ribble, a member of the new center's planning committee. "It has resulted in more team-teaching. And faculty are engaged in more cutting-edge, collaborative research." Trinity has some numbers to show for that. A survey of 46 faculty members found that eight have introduced new courses, new topics in existing courses or taught a course with another faculty member since the new buildings opened. And 18 professors said they have changed their teaching methods.[70]

Professors have also significantly reversed their negative opinions of the school's science facilities. For example, an EYP survey of faculty found 90% rated the previous labs as poor or average. Now 80% rate the new labs as good or excellent.[71]

The building has not only boosted team teaching and interdisciplinary research and lab work, but has also markedly increased social interactions, according to Professor Ribble. And he believes that's just as critical to learning and research as are better teaching methods. "CSI has made me realize how important social dynamics are to effective teaching," he adds. "I am a field biologist, so I have long understood how important the social/community aspects are to teaching and learning. You see this on extended field trips when students bond, learn about each other, and become better learners. Living and learning in CSI is like an extended field trip where you enjoy each other's company, work and play in an appealing setting."

For students interested in applying to Trinity, the building demonstrates "how great a community Trinity is to learn, grow and discover (in)," he says.

In the project, EYP emphasized sustainable and energy-saving design, while using elements such as limestone walls that nod to the history and geology of the site, and the architectural heritage of San Antonio. (The energy-saving measures helped Trinity University earn a $1.3 million rebate from CPS Energy, San Antonio's utility.)

Today, CSI has become a true home base where students want to hang out, socialize and study, Professor Ribble says. "We wanted it to be a home for all students, not just STEM students, and our studies indicate it is such a place." The evidence? Surveys of students have found that 95% of students have been to the new buildings more than 20 times. Before the new science buildings opened, some 25% of students had never wandered into the old science buildings. What's more, 40% of non-STEM Trinity students surveyed said the new science buildings have inspired them to learn more about science.

Trinity University
Center for the Sciences & Innovation

/ Acknowledgments

The expertise and stories in this paper are the product of many people. We'd particularly like to thank Charles Weiss and Royce Singleton, for their support, encouragement, and help creating our research methodology and tools, and Doug Weldon, for his support during the past 16 years.

And thank you to our STEM clients over the past 20 years for their commitment to the idea that architecture can influence learning:

- Assumption College
- Boston University
- Cabrini College
- Carleton College
- College of New Jersey
- College of the Holy Cross
- College of William & Mary
- College of Wooster
- Concordia College
- CUNY, Sophie Davis School
- Emory University
- Franklin & Marshall College
- Hamilton College
- Hampden Sydney College
- Haverford College
- James Madison University
- Lehigh University
- Massachusetts College of Liberal Arts
- Middle Tennessee State University
- Monmouth University
- Mount Holyoke College
- Mount Saint Mary College
- New York University
- Penn State University
- Radford University
- Roanoke College
- Rollins College
- Stanford University
- Stockton University
- Swarthmore College
- Texas A&M University
- Trinity University
- Union College
- University of Maryland, Baltimore County
- University of New Hampshire
- University of North Carolina at Pembroke
- University of Richmond
- University of Scranton
- Washington & Jefferson College
- Wheaton College
- Williams College

/ Endnotes

[1]National Center for Education Statistics, Table 317.10, number of 4-year degree-granting post-secondary institutions (public and private). The number of institutions (including branch campuses) rose from 2,363 in 1999-200, to 3,026 in 2012-13. http://nces.ed.gov/programs/digest/d13/tables/dt13_317.10.asp

[2]Bain & Company and Sterling Partners, "The financially sustainable university," by Jeff Denneen and Tom Dretler. July 6, 2012. http://www.bain.com/publications/articles/financially-sustainable-university.aspx The companies categorized financially unsound institutions as those whose equity and expense ratios were significantly weaker than they had been several years before.

[3]Jon Marcus, "Why some small colleges are in big trouble," Boston Globe, April 14, 2013. The reporter interviewed study co-author Jeff Denneen of Bain. https://www.bostonglobe.com/magazine/2013/04/13/are-small-private-colleges-trouble/ndlYSWVGFAUjYVVWkqnjfK/story.html

[4]According to the Federal Student Aid (FSA) office of the Department of Education, FSA can decide to heighten cash monitoring to increase oversight for certain financial or federal compliance issues. To participate in Title IV programs, the Department of Education requires for- and non-profit institutions to annual provide audited financial statements. The Department says it focuses on three financial ratios to assess financial health. More information at these Federal Student Aid webpages: https://studentaid.ed.gov/sa/about/data-center/school/hcm and https://studentaid.ed.gov/sa/about/data-center/school/composite-scores

[5]Inside Higher Ed, March 31, 2015. https://www.insidehighered.com/news/2015/03/31/education-department-names-most-colleges-facing-heightened-scrutiny-federal

[6]Moody's Investors Service document, "US higher education outlook revised to stable as revenues stabilize." July 20, 2015. https://www.moodys.com/research/Moodys-US-higher-education-outlook-revised-to-stable-as-revenues--PR_330530

[7]Moody's Investors Service press release, "Small but notable rise expected in closures, mergers for smaller US colleges," Sept. 25, 2015. https://www.moodys.com/research/Moodys-Small-but-notable-rise-expected-in-closures-mergers-for--PR_335314 We must note that for four-year higher education institutions overall, Moody's raised its outlook last year to "stable" from "negative," a designation the sector had earned beginning in January 2013.

[8]Moody's January 5, 2014 presentation to The Council of Independent Colleges, "The Financial and Strategic Outlook for Private Colleges in the New Economy," CIC 2014 Presidents Institute. http://www.cic.edu/News-and-Publications/Multimedia-Library/CICConferencePresentations/2014%20Presidents%20Institute/20140105-The%20Financial%20and%20Strategic%20Outlook%20for%20Private%20Colleges%201.pdf

[9]Inside Higher Ed, July 15, 2015. https://www.insidehighered.com/news/survey/closure-concerns-and-financial-strategies-survey-college-business-officers

[10]Michael McDonald, "Small Colleges Get an F in Finance," Bloomberg Business, April 24, 2014. http://www.bloomberg.com/bw/articles/2014-04-24/small-colleges-fight-enrollment-drops-with-tuition-discounts

[11]Tamar Lewin, The New York Times, "As Interest Fades in the Humanities, Colleges Worry," Oct. 30, 2013. http://www.nytimes.com/2013/10/31/education/as-interest-fades-in-the-humanities-colleges-worry.html

[12]Patricia Cohen, "A Rising Call to Promote STEM Education and Cut Liberal Arts Funding," The New York times, Feb. 21, 2016. Cohen cited a salary survey by the National Association of Colleges and Employers. The survey found the average STEM graduate salary in 2016 would be almost $65,000 – nearly $20,000 more than the average humanities graduate (at about $46,000). The NACE survey can be found here: https://www.naceweb.org/uploadedFiles/Content/static-assets/downloads/executive-summary/2016-january-salary-survey-executive-summary.pdf

[13]Whitehouse.gov. "Federal Science, Technology, Engineering and Mathematics (STEM) Education 5-Year Strategic Plan," May 2013, Office of the President of the U.S. https://www.whitehouse.gov/sites/default/files/microsites/ostp/stem_stratplan_2013.pdf

[14]National Science Foundation. http://www.humanitiesindicators.org/content/indicatordoc.aspx?i=386

[15]National Science Foundation statistics. http://www.humanitiesindicators.org/content/indicatordoc.aspx?i=387

[16]National Center for Education Statistics, Institute of Education Sciences, 2013 Digest of Education Statistics, Table 318.20. https://nces.ed.gov/programs/digest/d13/tables/dt13_318.20.asp

[17]Daily Camera, July 9, 2015 by Sarah Kuta. http://www.dailycamera.com/cu-news/ci_28462090/increasing-stem-enrollments-causing-cu-spend-more

[18]Daily Camera, Dec. 8, 2014. http://www.dailycamera.com/cu-news/ci_27095591/cu-boulder-group-study-declining-arts-and-humanities

[19]Daily Camera, July 9, 2015, article by Sarah Kuta, quoted CU Chief Financial Officer Todd Saliman. http://www.dailycamera.com/cu-news/ci_28462090/increasing-stem-enrollments-causing-cu-spend-more

[20]U.S. Department of Education, Institute of Education Sciences, National Center for Education Statistics, Table 318.20. https://nces.ed.gov/programs/digest/d13/tables/dt13_318.20.asp

[21]U.S. Department of Education, National Center for Education Statistics 2013 report, Paths Into and Out of STEM Fields," by Xianglei Chen and Matthew Soldner. http://nces.ed.gov/pubs2014/2014001rev.pdf

[22]According to a Georgia State University press release, Oct. 15, 2015. http://www.eurekalert.org/pub_releases/2015-10/gsu-srs101515.php

[23]Engage and Excel report by the President's Council of Advisors on Science and Technology, February 2012. https://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-engage-to-excel-final_2-25-12.pdf

[24]National Science Foundation document, Science and Engineering Indicators 2012, Chapter 2, p. 2-32. http://www.nsf.gov/statistics/seind12/pdf/c02.pdf

[25]Pranav Sharma and Eva Bogaty, Moody's Investors Service document, Dec. 2, 2015, pp. 4-5. https://custom.cvent.com/F60DFB3369884BF783A901B62EBC46B3/files/bf33bf8d7576447d87c73dc7cac947ad.pdf

[26]Sarah Grant, Bloomberg Business, "Can Small Colleges Save Themselves From the 'Death Spiral'?" Sept. 30, 2015. http://www.bloomberg.com/news/articles/2015-09-30/can-small-colleges-save-themselves-from-the-death-spiral-

[27]Bain & Co., "The Financially Sustainable University," p. 5. http://www.bain.com/Images/BAIN_BRIEF_The_financially_sustainable_university.pdf

[28]National Science Foundation, National Center for Science and Engineering Statistics, Survey of Science and Engineering Research Facilities, FY 2013, p. 87. http://www.nsf.gov/statistics/2015/nsf15320/pdf/nsf15320.pdf

[29]EYP research report on the impact of the Taylor Science Center at Hamilton College, by Leila Kamal, Toni Loiacano, Royce Singleton Jr. and Gordon Hewitt. November 2015. p. 8.

[30]University of Vermont website. "The Case for STEM," remarks to the UVM Board of Trustees letter from Provost David Rosowsky. http://www.uvm.edu/provost/The%20Case%20for%20STEM.pdf

[31]University of Mississippi news release, Sept. 4, 2015. http://news.olemiss.edu/ford-foundation-ups-commitment-25-million-um-science-building/

[32]EYP research report (p. 17), "Assessment of the College of the Holy Cross Integrated Science Complex II," October 2013, by Leila Kamal, Royce Singleton Jr., Charles Kirby, Kip Ellis, and Toni Loiacano.

[33]Ibid, p. 15.

[34]EYP website report on Holy Cross. Some 82% of faculty surveyed agreed or agreed strongly with the statement that "I carry out my research more quickly and efficiently." http://eypae.com/stem-impact/introduction

[35]EYP research report, "Assessment of the Impact of the Taylor Science Center, Hamilton College," November 2015, by Leila Kamal, Toni Loiacano, Royce Singleton Jr., and Gordon Hewitt.

[36]Ibid. The study authors say other factors may have come into play, including the nationwide increase in bachelor's degrees earned in the natural sciences and mathematics over that time period.

[37]EYP research report, "Assessment of the Impact of the Taylor Science Center, Hamilton College," November 2015, by Leila Kamal, Toni Loiacano, Royce Singleton Jr., and Gordon Hewitt. P. 15 and 16

[38]See "Live-Learn Research Report: University of Michigan," June 2014, published by EYP. http://eypaedesign.com/resources/media/publications/research-publications/live-learn-research-report-university-of-michigan.pdf

[39]EYP research, http://eypaedesign.com/stem-impact/destination-place

[40]EYP research, http://eypaedesign.com/stem-impact/effective-interaction

[41]EYP research, http://eypaedesign.com/stem-impact/informal-learning

[42]See this EYP microsite, http://eypaedesign.com/stem-impact/informal-learning

[43]EYP press release, http://eypaedesign.com/resources/media/press-releases/EYP-press-release-1332881465.pdf)

[44]Holy Cross website. http://holycross.edu/academics/programs/chemistry/our-programs/discovery-program

[45]EYP research, http://eypaedesign.com/stem-impact/teaching-labs

[46]EYP research, http://eypaedesign.com/stem-impact/teaching-labs

[47]EYP microsite. http://eypaedesign.com/stem-impact/engaging-visibility

[48]Ibid

[49]EYP research, http://eypaedesign.com/stem-impact/research-labs

[50]EYP research, http://eypaedesign.com/stem-impact/research-labs

[51]Educational Policy Institute press release on study by Dr. Neal Raisman, Feb. 6, 2013. http://educationalpolicy.org/news/PR/130206_Raisman.html

[52]EYP research report, "Assessment of the Impact of the Taylor Science Center, Hamilton College," November 2015, by Leila Kamal, Toni Loiacano, Royce Singleton Jr., and Gordon Hewitt, p. 10

[53]EYP research report, "Assessment of the Impact of the Taylor Science Center, Hamilton College," November 2015, by Leila Kamal, Toni Loiacano, Royce Singleton Jr., and Gordon Hewitt. On p. 15, the report explains other factors that could have increased the number of students majoring in science, including an increase in students with double majors and the national increase in science majors in that period.

[54]EYP microsite. http://eypaedesign.com/stem-impact/teaching-labs

[55]EDC Inc. "Improving STEM Curriculum and Instruction." http://successfulstemeducation.org/resources/improving-stem-curriculum-and-instruction-engaging-students-and-raising-standards

[56]April 2012 HBR article, "The New Science of Building Great Teams."

[57]http://cen.acs.org/articles/92/i20/Pros-Cons-Open-Plan-Science.html)

[58]Crick Institute webpage, https://www.crick.ac.uk/the-new-building/

[59]Kathy Chin Leong, "Samsung's New Open-Plan HQ Looks to Lighten San Jose," Fast Company, Sept. 29, 2015. http://www.fastcodesign.com/3051639/samsungs-new-open-plan-hq-looks-to-lighten-san-jose

[60]Ben Waber, Jennifer Magnolfi, and Greg Lindsay, "Workspaces That Move People," Harvard Business Review, October 2014, https://hbr.org/2014/10/workspaces-that-move-people

[61]EYP research, http://eypaedesign.com/stem-impact/teaching-labs

[62]Stephan Monterde, Cisco Systems director of corporate development, in a Sept. 17, 2015 blog post, "Where is Technology Innovation Heading?" https://www.linkedin.com/pulse/where-technology-innovation-heading-stephan-monterde?trk=prof-post

[63]Presentation by Kip Ellis (principal, EYP), Charles Kirby (principal, EYP), and Scott Merrill (director physical plant, College of the Holy Cross) at Tradeline Conference 2010, "Financial models for turning antiquated science buildings." https://vimeo.com/17614782

[64]University of Vermont alumni web page. https://alumni.uvm.edu/foundation/stem/

[65]Holy Cross website. http://holycross.edu/academics/programs/chemistry/our-programs/discovery-program

[66]EYP survey of 305 students, http://eypae.com/stem-impact/introduction

[67]EYP research report (p. 17), "Assessment of the College of the Holy Cross Integrated Science Complex II," October 2013, by Leila Kamal, Royce Singleton Jr., Charles Kirby, Kip Ellis, and Toni Loiacano. Of course, the number of graduates with chemistry majors in 2016 (58) may change by the time of graduation.

[68]From a July 2014 article in San Antonio's Rivard Report. http://therivardreport.com/trinity-university-center-for-the-sciences-and-innovation/

[69]Trinity University's Trinity Magazine, July 2014, p. 16. https://issuu.com/trinity_u/docs/trinitymagazine-july2014

[70]From an EYP report, "Assessment of Trinity University's Center for the Sciences and Innovation," February 2016. The report is based on research by Toni Loiacano of EYP and Royce Singleton Jr., Professor emeritus of Sociology, College of the Holy Cross.

[71]Ibid

EYP/

eypae.com

expertise driven design