Executive Summary

This report shares some lessons on supporting makers drawn from the experience and practices of the Massachusetts Institute of Technology (MIT). It is intended to support the inaugural White House Maker Faire\(^1\) as part of a package of similar reports from several institutions which will together provide educators, policymakers, and administrators with some insight into how universities might better support maker-minded students.

In brief, MIT supports maker students by a) designing admissions policies and processes to evaluate and admit students with high “maker potential,” b) offering a comprehensive set of hands-on project/product-based classes and research opportunities, c) providing radically available student machine shops and maker spaces, and d) building a “critical mass” of makers who in turn perpetuate a deeply ingrained culture of making.

Introduction: A Brief History of “Learning By Doing” at MIT

The Massachusetts Institute of Technology (MIT) was founded in 1861 with what today we would call “makers” in mind. At the time, college reached only a tiny fraction of the population and centered on Latin and Greek learned by rote. By contrast, William Barton Rogers, MIT’s founder and first president, organized the Institute around the principle of “learning by doing.”\(^2\) By

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engaging students in direct scientific experimentation and real-world problem-solving, the MIT model aimed to develop mastery of both mind and hand, theory and practice, to prepare students for careers in the “useful arts” of invention, design, manufacture, and craft. By 1869, MIT chemistry professor Charles Eliot, who would soon be named president of Harvard, described this “new education” as the “most ample course of instruction which has been thus far offered in this country to students who demand a liberal and practical education as well as a training specially adapted to make them ultimately good engineers, manufacturers, architects, chemists, merchants, teachers of science, or directors of mines and industrial works.”

In 1919, MIT’s President Richard Maclaurin spoke of an “extraordinary demand...for [the] technically trained [because] the social unrest that characterizes our time will not pass with mere talk.” Today, almost a century later, the nation’s need for innovative, creative, technically adept “makers” remains as urgent as it is timeless. It is in this context that the White House recently announced its first Maker Faire to “inspire more people to become entrepreneurs and to pursue careers in design, advanced manufacturing, and the related fields of science, technology, engineering and mathematics (STEM).”

This report contributes to this initiative by providing an overview of some ways that MIT supports makers on its campus and in its community from admission through graduation. We do not propose this as a fixed set of recommendations, or a universal “DIY” parts list for making more makers; leaders at each college and university will have to decide, based on their own constraints, priorities, and cultures, whether and how to support makers at their own institutions. This report can, however, provide policymakers, educators, and administrators with insights MIT has extracted from long experience and present practice.

Section 1: Developing a Maker Pipeline to MIT

Like any selective university, MIT can only offer admission to a small subset of its many qualified applicants. We choose this cohort through an admissions process that balances many competing institutional and public interests to appropriately allocate scarce spots and compose the best possible class. In general, the more selective the university, the more intentional it must be in designing an admissions process capable of identifying, evaluating, and appreciating the sorts of students it wishes to admit and enroll.

MIT Admissions recently introduced a “Maker Portfolio” to standardize the process of

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3 See [http://en.wikipedia.org/wiki/Useful_art](http://en.wikipedia.org/wiki/Useful_art); n.b.: “art” is used here in the same sense as “artisan.”
identifying and evaluating students who self-identify as makers. The process is analogous to those that MIT and many other institutions already use to identify artists, musicians, academic stars, etc.

In brief: applicants may choose to submit a Maker Portfolio, following instructions on the MIT Admissions website. Portfolios are then assigned to and reviewed by members of MIT’s Engineering Advisory Board (EAB) based on the relevant area of technical and/or creative expertise. Using a scale of 1-5, the EAB may rate the “Talent” and “Impact” evident in each portfolio, as well as providing an explanation of its significance, which serves as a very useful guide for the largely non-technical admissions officers who must make decisions.

Maker portfolios may not capture all aspects or forms of an applicant’s creativity, technical aptitude, etc., and even a strong EAB recommendation is only one of many factors in a given application. However, Maker Portfolios do provide a powerful tool for helping admissions officers identify, understand, evaluate, and admit exceptionally skilled applicants whom a conventional selective admissions process might undervalue or overlook altogether.

In addition to its Maker Portfolio, MIT’s Office of Admissions maintains strategic partnerships with many maker-minded programs, activities, and initiatives. These partnerships both a) communicate the value of these programs to and b) raise awareness about MIT among participants.

For example, MIT Admissions maintains a close relationship with FIRST Robotics, for which officers have attended regional and national events, presented awards, hosted participants on campus, etc. MIT Admissions officers have also spoken at Maker Faires, judged high school hackathons, and regularly visit specialized STEM high schools to speak with students, teachers, and counselors.

These kinds of partnerships are often comparatively simple and inexpensive to form but yield lasting benefits to MIT’s reputation, visibility, and relationship with maker communities. Indeed, 78% of MIT undergraduates surveyed reported that MIT’s reputation for being a maker-friendly

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8 Wendell, “Introducing...Maker Portfolios!”, MITAdmissions.org, August 2013, http://mitadmissions.org/blogs/entry/introducing...­maker­portfolios. MIT had long considered an applicant’s technical and creative aptitude through informal, ad-hoc processes since at least the late 1960s (and very probably well before). However, as MIT became more selective, the risks of these students being underidentified, underappreciated, and ultimately crowded out increased, prompting the development of this more formalized, standardized process.
10 See http://www.usfirst.org/aboutus/vision
12 E.g., the 2014 Blueprint hackathon at Google Cambridge, http://blueprint.hackmit.org
13 See, e.g., http://www.ncsssmst.org, but also local vocational schools and other hands-on institutions.
institutions made them more likely to enroll.\textsuperscript{14}

Section 2: Operating a Hands-On Academic Enterprise

MIT’s Latin motto, \textit{Mens et Manus} (Mind and Hand), emphasizes an ideal union of practical skill with theoretical understanding. The Institute’s academic enterprise has been designed to train students both to know how to make things \textit{and} to grasp why the things they make work.

For example, laboratory experience is required of all MIT students as part of the General Institute Requirements (GIRs).\textsuperscript{15} Through the GIRs, even students majoring in the humanities, arts, and social sciences are required to take \textit{at least} one laboratory class to help build their technical capacity. Even classes without the “laboratory” designation will often feature significant experimental, technical components, and not only in the sciences. For example, in Spring 2014, students taking CMS.400, a core course in the Comparative Media Studies humanities major, were required to learn and use data scraping and visualization tools to better understand the social world. The prevalence of “hands-on” classes allows (in fact, requires) all MIT students to learn techniques for making, even if they arrive with no prior experience or inclination.

Indeed, many “classic” MIT courses require students to design and manufacture a project \textit{and/or} product. 85\% of undergraduates surveyed\textsuperscript{16} have taken or intend to take such a class while at MIT, some of which include:

- \textbf{2.00b, Toy Product Design}, for which students prototype and invent new toys\textsuperscript{17}
- \textbf{2.007, Design and Manufacturing I}, which served as one of the inspirations for FIRST Robotics\textsuperscript{18}
- \textbf{2.009, Product Engineering Processes}, in which students quite often translate their final projects into real-world products and/or companies\textsuperscript{19}
- \textbf{6.005, Elements of Software Construction}, in which students learn the basics of software and application development\textsuperscript{20}
- \textbf{MAS.863/4.140, How To Make (Almost) Anything}, in which students are introduced to many methods of rapid prototyping and manufacture\textsuperscript{21}

\textsuperscript{14} “Makers @ MIT” undergraduate survey, conducted March 2014 (n = 701).
\textsuperscript{15} See \url{http://web.mit.edu/catalog/overv_chap3-gir.html#fr}
\textsuperscript{16} “Makers @ MIT” survey, \textit{op. cit.}
\textsuperscript{17} See \url{http://ocw.mit.edu/courses/mechanical-engineering/2-00b-toy-product-design-spring-2008/}
\textsuperscript{18} See \url{http://ocw.mit.edu/courses/mechanical-engineering/2-007-design-and-manufacturing-i-spring-2009/}
\textsuperscript{19} See \url{http://ocw.mit.edu/courses/special-programs/sp-724-prototypes-to-products-fall-2005/}. See, e.g., HelmetHub, a company which was started by students who “won” 2.009 by creating a vending machine for helmets to serve Boston’s growing bikeshare program, \url{http://www.helmet-hub.com/boston-case-study}
\textsuperscript{20} See \url{http://ocw.mit.edu/courses/electrical-engineering-and-computer-science/6-005-elements-of-software-construction-fall-2011/}
\textsuperscript{21} See \url{http://fab.cba.mit.edu/classes/MAS.863/}
Beyond these full semester classes, MIT’s Independent Activities Period each January features highly subscribed courses and competitions in areas like blacksmithing, web programming, and LEGO Robotics. 6.270, *Autonomous Robot Design*, in which students build fully autonomous LEGO robots, is so popular that the final competition for class projects must be held in MIT’s largest lecture hall and is broadcast over the web for an overflow audience.

**Outside of class, students develop hands-on experience through undergraduate research.** In 1969, MIT launched a then-novel program called the Undergraduate Research Opportunities Program, or UROP. What began as a small experiment is today a signature aspect of the MIT undergraduate experience; through UROP, 85% of MIT undergraduates will participate in frontline research before they graduate. Today, many institutions now offer undergraduates formal paths to research, but the rate of participation at MIT is, to the best of the Institute’s knowledge, dramatically higher than at any peer institution.

UROP offers students a wide range of opportunities to build their technical skills by learning research methods under the supervision of a faculty member. A UROP assignment might challenge students to design, discover, or invent innovative, applicable devices or processes, such as new batteries, photonic crystals, and augmented reality interfaces. The BeaverWorks Center, operated jointly with MIT Lincoln Labs, offers still more student opportunities for individual and/or collaborative hands-on research, working side by side with senior research mentors.

The many maker-minded members of the MIT faculty serve as mentors and role models for students. Professor Neil Gershenfeld, the Director of MIT’s Center for Bits and Atoms, supports a global network of Fab Labs which provide public access to digital fabrication tools. Professor Neri Oxman, a decorated designer and architect, develops manufacturing methods inspired by biological systems. Professor Martin Culpepper, associate director of MIT’s Lab for Manufacturing and Productivity, was recently appointed to the new position of “Maker Czar” at MIT, where he serves as the voice of the makers and builders in the Mechanical Engineering department and provides oversight of its machine shops. These faculty, like countless others at MIT, support and inspire maker students through their teaching, direct research opportunities, and academic advocacy.

**Section 3: Maintaining a Maker-Friendly Infrastructure**

Makers require an infrastructure that supports their ability to make things. This infrastructure

23 See http://techtv.mit.edu/videos/23865-urop-profile-allan-blanchard
25 See http://techtv.mit.edu/collections/dunoyercuts/videos/23888-lumninar-urop
26 See http://engineering.mit.edu/programs/beaverworks
27 See http://ng.cba.mit.edu/neil/bio.html; see also http://cba.mit.edu/docs/papers/12.09.FA.pdf
28 See http://web.media.mit.edu/~neri/site/about/about.html; http://matter.media.mit.edu/about
29 See http://newsoffice.mit.edu/2013/meche-announces-three-new-appointments
includes a robust physical/technical plant and relatively open use policies.

Like most technical universities, MIT has many shops that students can use for completing projects for their coursework. For example, the Pappalardo Lab is the principal machine shop for Course 2 (Mechanical Engineering). Students who take Course 2 classes are often assigned areas within the Pappalardo Lab, where staff then train them on the safe use of the equipment. Similarly, the Glass Lab and Forge operated by Course 3 (Materials Science) also offer popular undergraduate classes in glassblowing and metalwork during the Independent Activities Period in January.

However, MIT also has several student shops available for nonacademic use. These shops serve as a vital complement to the shops owned and operated by departments because they offer students a comparatively available and unrestricted facility in which to (safely) make the things they are inspired to make, often with no connection to their coursework whatsoever. Some of the most prominent include:

- The Edgerton Center Shop supports both individual students and a dozen student-led teams with priority access to CNC machines, manufacturing equipment, insurance, funding, and training. Teams have designed and built solar cars, rockets, underwater gliders, and more for competitions and/or their own satisfaction.
- The Edgerton Student Shop, which provides free machine training and in which students spend nearly 6,000 cumulative hours annually (including nights and weekends).
- The MIT Hobby Shop, which since 1938 has offered students a place to make things, with staff and machines funded by membership dues.
- The Center for Bits and Atoms, which manages a facility for making and measuring things on length scales from atoms to buildings.
- MIT Electronic Research Society (MITERS), a completely student-run, self-funded, build-anything-you-want hackerspace.

Some MIT dormitories and independent living groups (ILGs) have also developed their own shops and maker spaces. These dorms and ILGs often have comparatively permissive policies allowing students to (safely) build things in and around the dorms; some even maintain a substantial inventory of tools which any resident can freely borrow and use. Students consistently credit the availability of space and tools in their living areas as factors which

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30 See http://mitadmissions.org/blogs/entry/machine_shops_part_1
31 See http://glasslab.mit.edu
32 See http://dmse.mit.edu/resources/foundry-and-forg
33 See http://asme.scripts.mit.edu/home/machine-shop-access-around-mit/
34 See http://edgerton.mit.edu/node/126.
35 See http://studentlife.mit.edu/hobbyshop/history
36 See http://fab.cba.mit.edu/content/tools/
37 See http://miters.mit.edu/about.php; for a short documentary on MITERS, see https://www.youtube.com/watch?v=jvLvdmiMQkU
substantially lower the “transaction costs” of making. Indeed, 64% of respondents reported they made things in their dorms or independent living groups: in bedrooms, lounges, and unused bike storage spaces. The ad hoc repurposing of dormitory space, as well as student-run hackerspaces such as MITERS, has evolved into a kind of alternative infrastructure for making which threads throughout the larger institution.

MIT supports those who make software in part by providing a remarkably fast, radically open Internet infrastructure. The single most common mode of making at MIT is programming: of the students surveyed, more than 60% code and make things “wherever my laptop is,” and more than a quarter have participated in a hackathon. Any infrastructure intended to support such students must allow them both to make new software and to share what they have made. MIT’s fast and unusually open Internet, as well as its public support of innovative technology, helps students to work thoughtfully and creatively without being unduly encumbered. Indeed, one recent MIT alumnus and successful entrepreneur described MIT’s Internet infrastructure as one of the most notable “perks” which enriched his undergraduate experience.

Section 4: Creating a Strong Maker Culture

So that we could offer observations based on more than impression and anecdote, we sent a simple survey to all MIT undergraduates, asking a series of questions about how, where, why, and with whom they made what they made.

Undergraduates consistently credit a strong community and culture as one of the aspects of MIT that best supports their making. As one respondent put it, being “surrounded by people working on interesting projects makes me want to join the party. If you don’t know how to do something there’s usually someone around who can help.” In addition to the academic enterprise and physical facilities, undergraduates rely heavily on each other as sources of inspiration, encouragement, and training for new things they can make, both inside and outside the classroom. Put another way: there are sufficient numbers of maker-minded students here that the intrinsic value of making things is taken for granted as a foundational element of the world which MIT students experience together, i.e., their culture.

41 For a statement reflecting MIT’s commitment to these goals, see e.g. Reif et al, “MIT’s Letter to New Jersey’s Attorney General,” March 2014, [https://www.eff.org/files/2014/03/07/mit_3.5.14_letter_re_tidbit.pdf](https://www.eff.org/files/2014/03/07/mit_3.5.14_letter_re_tidbit.pdf)
42 Mills, “Perkus Nonacademia,” October 2010, [http://mitadmissions.org/blogs/entry/perkus_nonacademia](http://mitadmissions.org/blogs/entry/perkus_nonacademia); Mills’ company HelmetHub, which manufactures helmet rental vending machines to complement Boston’s bikeshare program, grew out of his final project for 2.009, one of the leading maker classes at MIT.
43 “Makers @ MIT” survey, op. cit.
There appears to be a “critical mass” of makers at MIT who collectively create and maintain a self-perpetuating culture of making on campus. Students variously characterize the maker mindset at MIT as a “general mentality,” a “pervasive idea,” and “a strong culture.” “Everybody is a maker!” one student exclaimed in her response. Some students are more accomplished makers than others, and they stand out as nodes in the social network to whom other students turn for inspiration or training. However, the critical mass is not manifest in a single, small dense core of “maker stars”; rather, it is diffused generally in a common willingness to develop technical expertise through actual practice.

MIT’s culture of making is passed down and reaffirmed by student traditions and activities that celebrate the value of creating beautiful, useful, ingenious and/or interesting things. Some of the major traditions, events, and policies mentioned by students in the survey include:

- Student “hacks,” i.e., creative, technically challenging pranks and general tomfoolery
- Dormitories that tolerate semi-permanent murals, construction projects, and other creative interventions within the building as long as they are completed safely
- Regular events, often during breaks in the academic calendar, when student communities take time to collaborate on creative projects together
- Popular extracurricular activities and associations for making robotics, vehicles, assistive technologies, and almost anything else

Our survey suggests that MIT’s maker culture may be the single strongest factor supporting makers on campus. This culture continues its vibrant development with the first MIT Maker Faire scheduled for fall 2014. If the academic enterprise and technical infrastructure are the railroad tracks, the culture is the steam animating the engine, the motive power that drives student projects along those tracks into a more innovative future.

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47 Ibid. at 16-17. See also, e.g., http://eastcamp.us/media.shtml#rex; http://eastcamp.us/media.shtml#cpw; http://eastcamp.us/media.shtml#bad_ideas
48 See http://web.mit.edu/uav/www/
49 See http://solar-cars.scripts.mit.edu/main/
50 See http://assistivetech.mit.edu/assistivetech/website/index.html
51 See http://miters.mit.edu
52 78% of respondents reported that MIT’s culture supported their making, more than any other aspect; additionally, only 4% of respondents reported that MIT’s culture failed to support their making, less than any other aspect. “Makers @ MIT” survey, op. cit.
53 See http://makerfaire.mit.edu
Conclusion: Paving Pathways to Maker-Friendly Futures

It is important to understand that the tradition of making now so fundamentally identified with MIT was not inevitable, but rather contingent, a consequence of many interlocking choices over time. MIT did not set out to invent this culture; rather, the institution and the culture emerged and evolved together. A sufficient number of students, their creative and technical inclinations reinforced by community rituals and enabled by a comparatively open academic and physical infrastructure, have, with their minds and hands, knit together a strong common culture that now both supports and drives their making moving forward. In this respect MIT intends for its future to be as bright as its past.54

Other universities have their own cultures, their own constraints, and their own opportunities; what has worked at MIT might neither fit nor function effectively elsewhere. But if we had to distill MIT’s experience into a few principles, they would center on:

- adapting the Admissions process to identify, encourage and develop a pipeline of students with maker potential
- consciously designing the academic program so that it encourages all students to engage in hands-on projects
- maintaining an open, low-barrier-to-entry physical and technical infrastructure that supports student experimentation, safe transgression, and creative play
- creating a culture that celebrates and reaffirms the intrinsic value of making things

The more maker-friendly universities become, the more makers they will make, and the more creative and innovative their shared future will be.

Appendix

Background
This white paper was prepared as part of a broad initiative supporting Making led by the White House Office of Science and Technology Policy (OSTP).55 It is intended to help provide educational officials in government and at universities with some insight from the MIT experience on how Makers can be supported on campuses through programs, infrastructure, and culture.

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54 See, e.g., the report by the Institute-wide Task Force on the Future of MIT Education at http://future.mit.edu, which suggests several ways in which MIT can support makers moving forward.
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