A Research Agenda for Academic Makerspaces

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INTRODUCTION

A key characteristic of academic makerspaces that distinguishes them from fab labs in secondary schools, non-profit community spaces, or for-profit membership facilities is of course that they are embedded in institutions with significant research activity. Yet academic makerspaces also differ from traditional research labs in that they are open to a broader set of constituents and expertise levels, and often support a larger variety of possible uses. While many emerging academic makerspaces are primarily associated with instruction and student service goals, we argue that research and making can and should intersect in productive ways. This paper lays out the landscape of possible engagements based on our own experience and observations.

A tight connection to academic research promises benefits for both sides:

1) Educational research and qualitative observational research can improve our fundamental understanding of the values of making for students; as well as elucidate the conceptual and pragmatic hurdles makers face today through careful study of making in practice.

2) Makers can serve as a new target audience for technology research and development in engineering disciplines.

3) Research projects in a large number of domains can leverage makerspace resources to accelerate their progress and engage students to turn fundamental discoveries into usable devices and services.

In addition to these intellectual threads, research integration can also contribute to important pragmatic and operational goals, for example ensuring that makerspaces receive appropriate institutional attention, credit, and funding.

We next present our own institutional context, review the three major themes listed above and present illustrative example projects.

CONTEXT

Our review of research integration opportunities is based on our experience launching and running two makerspaces for the past four years at UC Berkeley within the College of Engineering (see Figure 1). The CITRIS Invention Lab, launched in 2012, started as a bottom-up effort to bring digital fabrication equipment out of restricted lab settings of individual faculty and make it available to the larger campus for teaching, independent project work, and research. The Invention Lab is located in a large, multi-disciplinary research building and has a focus on supporting researchers and university startups. Our experience in launching the Invention Lab strongly informed the design of the Jacobs Institute for Design Innovation, a 24,000sq ft building with three teaching studios, a 7,000sq ft maker space, and advanced fabrication and electronics labs spread throughout four floors. One of the main missions of the Jacobs Institute is to impact undergraduate education at UC Berkeley. An important feature of our programming in both locations is that community space, classroom space, and fabrication labs are all co-located, and that intersections between different cohorts of undergraduate students, graduate researchers, faculty and staff are explicitly encouraged.

Figure 1 - Top: The Jacobs Institute for Design Innovation at UC Berkeley. Bottom: Students working in Berkeley's CITRIS Invention Lab.

THEME 1: UNDERSTANDING THE VALUE OF MAKING AND HOW MAKING HAPPENS IN PRACTICE

Academic makerspaces offer easy access for education researchers who wish to study the impact of making-based curricula on STEM preparation and other learning outcomes. Claims in the maker movement about increases in self-efficacy or motivation towards STEM careers abound. But how can we rigorously test whether this is indeed the case? A growing body of research is investigating the impact of making, including crucial questions round what the right metrics for impact are [1,2]. Some existing research focuses on K-12 education [3], or specialized education settings [4]. There is significant need and opportunity to contribute sound assessments at the college level. The learning sciences provide relevant theories, such as constructionism

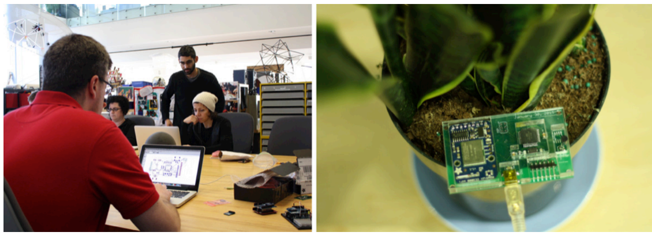

Figure 2: Makerspaces can serve as locations for qualitative research, such as Mellis et al,'s investigation into how novices approach circuit board design [8].

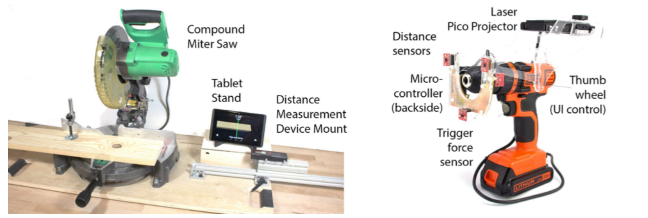

Figure 3: Augmented power tools by Schoop et al. [15] aim to deliver dynamic tutorials to tool users.

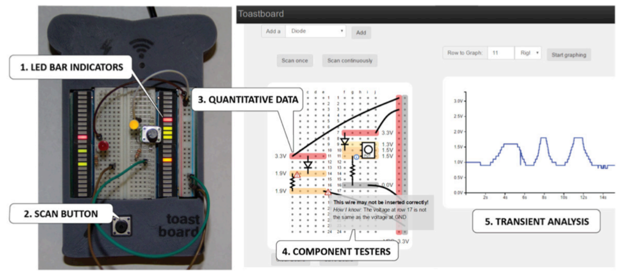

Figure 4: The Toastboard, an augmented breadboard for troubleshooting circuits by Drew et al. [20].

and project-based learning, and appropriate assessment methodologies, such as comparisons of pre- and post-tests and surveys of students engaged in makerspace activities and classes. It would be especially enlightening to find settings where such results can be compared against matching activities that take place without access to a makerspace. In the Jacobs Institute, we plan on hosting a graduate research course on pedagogy and assessment in engineering design education, led by Prof. Alice Agogino, where graduate students will be embedded as observers of the making activities in the building.

In addition to *formal* education, researchers are also seeking to gain insight into *informal* learning by makers – e.g., understanding how online tutorials, project sharing sites or communities help or confuse individuals [5,6,7]. Our collaborators have used community workshops located in academic makerspaces to investigate how a broader public can become engaged in the fabrication of electronic products [8] (see Figure 2). Such studies shed light on the role of informal networks of expertise sharing, and they can also result in guidelines for the design of better future technologies that overcome hurdles that individuals makers and groups experience today.

THEME 2: ENVISIONING THE FUTURE OF MAKING: DESIGNING TECHNOLOGIES FOR MAKERS

Because of the institutional support for developing and evaluating novel, experimental technologies, academic makerspaces are also ideally positioned to push the boundaries of the hardware and software tools that are found in such spaces. Different engineering disciplines from Computer Science to Electrical Engineering and Mechanical Engineering are increasingly becoming interested in developing technologies that are tailored to makers as target users. Academic makerspaces can also help disseminate the most promising technologies through workshops and through developing and publishing documentation, tutorials, and example projects.

A. DESIGN SOFTWARE

One strand of recent research provides improved design software for existing digital fabrication equipment in such spaces. For example, in our own work we have developed design tools for modeling, routing and fabricating hollow tubes inside 3D-printed objects, which can then be filled with conductive materials to integrate electronic components or create interactive, touch-sensitive objects (released in Autodesk's Meshmixer) [9]. Others have developed algorithms to 3D print "wireframe" models an order of magnitude faster than solid 3D models [10], or computationally modify models to create tactile textures [11], or articulated figures [12]. One advantage of such software advances is that wide distribution is simple. However, making the transition from a research prototype to robust software with appropriate maintenance and support is at not always aligned with researchers' academic career incentives.

B. FABRICATION HARDWARE

Researchers are also developing novel hardware tools – from CNC felting machines [13], to actuated hand-held carving tools [14] and augmented drills and saws [15] (Figure 3). These explorations can most profoundly re-envision what future makerspaces will look like and how makers will interact with their tools.

C. EMBEDDED CODE AND ELECTRONICS

Many projects created in makerspaces include embedded code and electronics. Moore's law and the success of accessible microcontroller platforms such as Arduino have lowered both the price and expertise barriers such that adding computation and interactivity has come within reach even for novices. Research labs have produced embedded computing platforms aimed at makers, e.g. for interactive textiles [16], or for connecting sensors to smart phones [17]. Because of maker-oriented electronics distributors such as Sparkfun, Adafruit and Seeed, these research projects are increasingly available to the larger community. In our own work we have focused on making the new "stack" for Internet of Things devices – embedded, smartphone and cloud – more easily programmable for makers [18].

One of the key challenges going forward will be to support makers in understanding and debugging the complexity of the cyber-physical systems they build in makerspaces [19]. For example, to support novices in circuit construction, we are developing an augmented breadboard that continuously scans voltages across all rows and visualizes discrepancies between intended and observed circuit behavior in a web interface [20] (Figure 4).

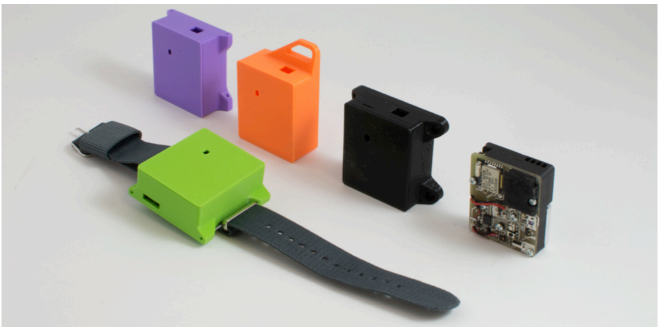

Figure 5: The MyPart wearable particle sensor research project by Tian et al. [23] was enabled by PCB milling, 3D printing and electronics equipment in the CITRIS Invention Lab.

THEME 3: MAKER RESOURCES AMPLIFY EXISTING RESEARCH

The equipment available in makerspaces, and the result-oriented, prototype-driven value system frequently found there, can support research in a wide variety of domains. While many scientific disciplines have developed highly specialized equipment, our experience has shown that the general-purpose fabrication tools in makerspaces have broad applications across many scientific fields. Furthermore, the relatively low expertise threshold for digital fabrication tools – when compared to traditional machining – means more researchers perceive working in a makerspace as within their reach.

For example, our labs have seen researchers build automated RFID rodent trackers, novel haptic actuators, spherical tensegrity robots, laser-cut water treatment devices, 3D printed microfluidic devices, pressure ulcer sensors, domed LED arrays for mobile microscopy [21], robotic floats that study the ocean's carbon cycles [22], and low-cost, wearable air particle sensors [23] (see Figure 5).

While such research is often federally or industrially funded and access fees are of little budgetary significance for PIs, we have found that merit-based fellowships that give free access to our makerspace are a very effective vehicle to raise awareness of our makerspace among graduate students. In addition to the resulting research itself, the mixing of highly trained doctoral students from various disciplines with undergraduates who are getting their first exposure to hands-on design is a tremendous positive for our lab culture.

Ideas that arise in graduate research groups can also serve as the basis for undergraduate student projects. A fundamental insight or discovery can be further explored, or moved towards a translation into a concrete product or service. Several project ideas that teams developed in the Jacobs Institute and Invention Lab originated as research projects in the medical school and medical center at the University of California, San Francisco. For example, a student group created pressure-sensing insoles for patients with sensory ataxia (loss of feeling) in the legs. The idea first arose in medical research; students in a class hosted in our makerspace then contributed engineering expertise to build a wireless prototype. Additional class projects based on medical center needs have included liquid tracking for nephrology patients, and methods to counteract patient delirium.

METRICS

Documenting the integration of research can be helpful in arguing for appropriate resources for makerspaces, and in showing how making activities connect to the core academic mission of knowledge production. In addition to examples and anecdotes such as the ones listed in this paper, we suggest that documentation should, at a minimum, comprise descriptive statistics on fundamental metrics such as:

- The number of research artifacts or instruments that were built in a makerspace.
- The number of papers published that were enabled by a makerspace.
- The number of research grants or gifts submitted and funded that leveraged a makerspace.
- The number of graduate, postdoctoral or professional researchers served.
- The number of undergraduate makerspace students who were involved in the research and were trained in research methods.

CONCLUSION

We have described three separate but complementary themes how research activity can be integrated into academic makerspaces. In addition to the intellectual value, research integration can also contribute to important pragmatic and operational goals, for example ensuring that makerspaces receive appropriate institutional attention, credit, and funding. Finally, the community benefits of creating spaces where both novices and experts cross paths are significant. We encourage other makerspaces to consider attracting and growing research engagements in their facilities.

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