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University Makerspaces and Manufacturing Collaboration: Lessons from the Pandemic

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The role of universities in addressing the needs of the manufacturing sector has been substantially evolving in the past decade because of macro trends and associated policy changes. Notably, the classic combination of lecture and laboratory courses has been augmented by open-ended exploration and hands-on skill development in university makerspaces.

Disruptions associated with the covid-19 pandemic have required new adaptations. The pandemic not only suspended existing practices but demanded that institutions assume new roles. University makerspace staff and resources were directed to support efforts related to research, design, manufacturing, and testing solutions. Such responses were possible because of the availability of academic talent in the technical operations required to make precise and complex articles and devices.

There is broad, if informal, recognition that things will not return to the state that existed before the pandemic, so reflecting on lessons learned and considering appropriate actions for the future is warranted.

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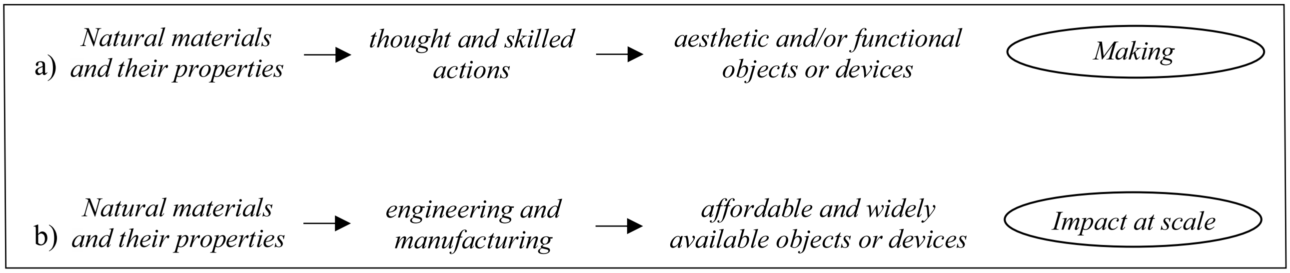

FIGURE 1 Expressions of making (a) and engineering (b).

Academic makerspaces can be leveraged and modified to strengthen the relationship between manufacturers and higher education in new ways. Experience suggests rich opportunities to guide universities in preparing students for a manufacturing career and, through research and technology transfer, to assist manufacturers in making effective use of newer technologies and scientific results.

Differences between Making and Manufacturing

Making and manufacturing are distinct but complementary and involve similar skills. Both are advanced by creativity and inventiveness. Making advances an idea into a prototype and manufacturing advances a prototype into a product.

The technical unit operations are the same, but making typically involves small production volumes, whereas manufacturing spans production volumes from single digits to millions of parts (Kalpakjian and Schmid 2020). And making as an enterprise is distinct from manufacturing as a profession. Fully half of Americans self-identify as makers (Lou and Peek 2016); less than 10 percent have manufacturing employment (Helper et al. 2012).

Academic makerspaces are conceptually connected to the long-recognized value of both experimentation and experience in learning (Kolb 2015). As a well-defined entity, they are traced to the MIT Fab Lab program that grew out of Neil Gershenfeld's course "How to Make (Almost) Anything" (Gershenfeld 2005). They now involve a network of alumni, regional manufacturers, material suppliers, and a broad array of users, with established processes to accept external inquiries. During the last decade (Barrett et al. 2015; Lou and Peek 2016) they have moved from being unusual to expected, and there has been serious study of the role and impact of academic and other makerspaces (Hilton et al. 2018; Rosenbaum and Hartmann 2017; Wilczynski et al. 2017).

The purpose of academic makerspaces is not specifically aligned with that of manufacturing. Manufacturing engineering represents only half of the discipline-specific skill development in typical academic makerspaces (Wigner et al. 2016), where exploration of design is a key facet (Wilczynski et al. 2017) and the reintroduction of prototyping and fabricating has been identified as an opportunity to link engineering skills to the humanities (Nieusma and Malazita 2016). In makerspaces participants learn and refine skills (such as design, fabrication, testing) to develop prototypes and single-user artifacts. Makerspaces also provide a comfortable and safe environment and a support system for the complete novice to acquire confidence while developing manufacturing-relevant technical skills.

To illustrate the distinction between making and manufacturing, it is helpful to consider two expressions inspired by those developed by Harms and colleagues (2004) in their analysis of the field of engineering (figure 1).

The first expression (figure 1a) represents the general process of transforming raw materials to effect a goal—that is, making something. It includes invention, prototyping, design of experiments, and artistic expression, as well as manufacturing. From this perspective, making is a form of thinking and creativity that complements abstract conceptualization and reflective observation, while demonstrating both how to work within constraints and how to leverage and synthesize knowledge.

In addition, as a general practice, the making community facilitates people working together and communicating so that needs and desires get translated into designs that can be realized. All of these facets help develop attributes sought by employers, including critical thinking and problem solving, communication skills, teamwork, and collaborative skills.

In making, the focus is on the characteristics of the product. Cost, time, and reproducibility are factors, but not prime considerations. In contrast, implicit in manufacturing is an awareness of the primacy of economics, the need for documentation to ensure repeatability, scalability, tolerances, risk management, conformance to standards, throughput, and capitalization of facilities, among other factors. Manufacturing supported by comprehensive engineering (figure 1b) offers societal benefit through widely available affordable devices that offer high performance and highly reliable operation.

The scale of mass manufacturing is not remotely approached in the context of making. For example, annual light vehicle production is more than 90 million worldwide (with a single popular model approaching or exceeding 0.75M units). Similarly, smartphone production exceeds 1.4 billion per year, and an astonishing 200 billion aluminum cans are produced each year.

Furthermore, the extremely low tolerance of risk associated with manufactured goods is generally not a guiding criterion in the context of making. Even with small production volumes, compliance with design specifications and industry standards is paramount with manufacturing, but typically not in the context of making, which is often done on a best-effort basis. Scaling up to production levels safely is a challenge for all industries (e.g., Fernandes et al. 2019; Reisman 1993; Ward et al. 2012), and the fact that it is so frequently accomplished is a testament to the professionalism and dedication of those involved.

Manufacturing enterprises that connect with universities have much to offer academic makerspaces in terms of reliability testing methods, case studies of solutions to seemingly intractable problems, dealing with constraints, strategies for decision making, and prioritization methods.

International Support for Academic-Industry Collaboration

The World Manufacturing Forum was established in 2018 as a collaboration of commercial enterprises, the academic sector, and associations with the mission of generating and diffusing a manufacturing culture around the world and goals of economic equity and sustainable development. Its report on the future of manufacturing includes ten short- and long-term recommendations, many of them relevant to university-based initiatives (Taisch et al. 2018):

1. Cultivate a positive perception of manufacturing
2. Promote education and skills development for societal wellbeing
3. Develop effective policies to support global business initiatives
4. Strengthen and expand infrastructures to enable future-oriented manufacturing
5. Encourage ecosystems for manufacturing innovation worldwide
6. Create attractive workplaces for all
7. Design and produce socially oriented products
8. Assist small and medium-sized enterprises with digital transformation
9. Explore the real value of data-driven cognitive manufacturing
10. Promote resource efficiency and country-specific environmental policies

One important response to the need for manufacturing-relevant research is a network of 15 institutes designated Manufacturing USA[1] (Molnar 2018). Its goals include facilitation of the transition of innovative technologies into scalable, cost-effective, and high-performing domestic manufacturing capabilities, and acceleration of the development of an advanced manufacturing workforce. In 2018 Manufacturing USA supported nearly 500 research and development projects and more than 200,000 students in associated STEM activities. In addition to its 244 government, government lab, and not-for-profit members, the public-private partnership includes 474 universities, colleges, and community colleges, and 1129 companies (371 large and 858 small manufacturers). Manufacturing USA has also been singled out for NSF support (Wang 2016).

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These developments set the stage for covid-19-motivated collaborations between manufacturers and academic makerspaces.

[1] https://www.manufacturingusa.com/institutes

Covid-19 and Important Contributions of Academic Makerspaces

In March 2020 most US institutions of higher education abruptly shifted from in-person on-campus instruction to remote learning, affecting as many as 14 million students (Hess 2020). One consequence was that user facilities such as academic makerspaces suddenly had excess capacity and assumed new roles. A number of them reconfigured to support their institutional mission, producing parts to support distance learning—such as classroom models and demonstration components—and projects, courses, and laboratories. Even while responding to these new demands, there was still often excess capacity.

The pandemic required leveraging existing and new relationships among makerspaces, regional healthcare providers, and manufacturers.

They were also able to respond to the pandemic directly, in partnership with the manufacturing community, by addressing needs, challenges, and opportunities related to the following realities:

- The existing supply chain was unable to meet the dramatic increase in demand for personal protective equipment (PPE).
- Traditional demand for many manufactured goods suffered a sudden drop, creating excess capacity.
- Supply chains, particularly those that drew on international suppliers, became rapidly depleted in raw materials.
- Standard operating procedures for entities that rely on close-proximity interactions with broad swaths of the population (e.g., health care, hospitality, and education) changed fundamentally—and these changes appear to be becoming institutionalized.

The early stages of the pandemic placed makerspaces in a surrogate manufacturing position, suddenly faced with challenges associated with inventory, supply chain, testing/certification, packaging, and distribution—all areas beyond their normal expertise. The distinction between making and manufacturing became immediately apparent. The PPE need, for example, was simply too large for makerspaces to address (e.g., Westervelt 2020). Impact required leveraging existing and new relationships among makerspaces, regional healthcare providers, and manufacturers.

Often, makerspaces served as a conduit to medical professionals, with industry, making, and manufacturing professionals working together in ad hoc teams to create solutions. Makerspace employees served as liaison or interpreter between clinical engineers and professional peers in manufacturing. This role illustrates a potentially important and transformative partnership that could be continued after the pandemic.

In other cases, makerspaces (and university research labs) fulfilled a quality assurance function in the manufacturing process when medical technology or PPE required performance verification. Makerspaces pivoted to create tests, evaluation systems, and processes to validate material that lacked external certification, such as respirators, surgical masks, and ventilator components. However, while these are standard operations for manufacturing industries, they are not commonly a component of makerspace operations, and the role of regulatory agency oversight for PPE and medical technology was perhaps underrecognized early on. Nevertheless, makerspace staff took care to ensure that potentially unsafe equipment was not introduced into the community. This represents another opportunity for manufacturers to work together with universities.

Illustrative Case Studies

To illustrate makerspace responses to the pandemic, we briefly review three case studies.

Academic Makers Collaborate to Produce Face Shields

At Case Western Reserve University (CWRU), the limited availability of face shields was an early priority in the pandemic. The shields have three components: headband, clear face shield, and rubber strap. An open-source design for a 3D-printed face shield was available (Prusa 2020), but the cycle time for production in the maker community was daunting.

The components can be produced in a makerspace using a combination of fused deposition for the headband and laser cutting for the clear face shield and rubber strap, but the cycle times are long relative to manufacturing operations: The cycle time to make 48 rubber straps using a laser cutter was about 48 minutes (60 sec each), whereas the same quantity could be manufactured by die cutting on a sheet-fed clicker die in about 1.5 minutes total (1.9 sec each). And to make two clear face shields using a laser cutter would take about 1 minute (30 sec each), whereas they could be manufactured by die cutting on a roll-fed clicker die in about 5 seconds total (2.5 sec each).

The largest time sink was for producing the headband. Making two headbands on an industrial 3D printer would take about 40 minutes (20 min each), whereas they could be manufactured by injection molding on a 2-cavity mold in about 8 seconds (4 sec each). In this example, making entailed a production rate of 3 units per hour whereas manufacturing yielded 900 units per hour. Multiple cavities and other standard techniques enabled more than a doubling of throughput using common manufacturing methods.

A team was formed with two universities, three manufacturers, and an industrial design firm (CWRU 2020).[2] A faculty member at one university designed injection molding tooling. The academic makerspace staff at the second university prototyped and validated adjustments to the original designs for molding and die cutting in consultation with the industrial designer and academics with relevant expertise. Manufacturing and logistics were handled by the companies.

It took less than 2 weeks to progress from idea to the start of production. The collaboration resulted in 150,000 face shields manufactured and delivered within 30 days—where no supply chain had existed. Collaboration with a local manufacturing extension partnership extended the impact to the scale of mass manufacturing (MAGNET 2020).

The critical takeaway is that if CWRU had tried to make face shields using only its own prototyping equipment it would have failed. The fact that the university's technically trained people reached out and formed partnerships allowed a nontraditional set of small manufacturing firms to produce face shields at rates comparable to those of large vertically integrated firms (e.g., 100,000/week by Ford in Troy, MI). The CWRU example shows that universities are gaining experience in real manufacturing and thereby developing experience that can foster better university-industry partnerships.

[2] White Label Face Shields, https://whitelabelfaceshields.com/

There are many other examples at CWRU and other universities. The lesson here is that the academic makerspace community quickly created holistic complementary teams and executed complicated projects under significant time pressure.

It will be valuable to incorporate this type of rapid response into standard operating procedures for academic makerspaces. Successfully confronting the challenge of true manufacturing, rather than prototyping, creates an experience base for universities to leverage in future partnerships with industrial firms.

Creation of Rapid Testing Capacity for Respirators

In another example, quality assurance principles commonly associated with manufacturing were applied at a university makerspace to ensure that PPE met specified standards.

The pandemic rapidly stressed the PPE supply chain in the Northeast United States, prompting hospitals to reach out beyond their normal vendors. For respirators, donated supplies and material from potential vendors were not always certified (by the National Institute for Occupational Safety and Health, NIOSH) as N95 respirators. In the absence of this certification, hospitals needed methods to evaluate respirator quality.

Makerspace staff designed and implemented a local respirator testing station based on NIOSH testing guidelines.

At Yale University a team was formed in late March 2020 to address this issue, with physicians and supply chain logisticians from the hospital, researchers and design staff at the university's makerspace (Yale Center for Engineering Innovation and Design), and faculty. With expertise in design, electronics, fabrication, and testing, makerspace staff served as the conduit between the medical and research communities to quickly design and implement a local respirator testing station based on NIOSH testing guidelines. Components for the testing station were manufactured on site.

The team created a test station to evaluate the efficiency and flow impedance of uncertified respirators. Performance tests documented the system's accuracy and precision, and the results were verified using independent measurement devices.

Many university makerspaces have space to jointly host outreach events with manufacturing firms.

At the height of the pandemic's spring wave, respirators arrived daily for testing, and the results on each mask's fit, efficiency, and flow impedance were provided within 24 hours. The method was published to enable others to develop local respirator testing platforms (Schilling et al. 2020).

An Academic-Industry-Federal Lab Collaboration

Another collaboration that included production of face shields underscores the distinction of making versus manufacturing in terms of production rates and raises other important points as well. This was a three-way partnership of the federal Manufacturing Demonstration Facility at Oak Ridge National Laboratory; the University of Tennessee, Knoxville, involving a faculty member in advanced composites and manufacturing innovation; and a global manufacturer of medical supplies (ORNL 2020).

The manufacturer, seeking to produce face shields, recognized the need for a new type of mold to increase production rates but did not have the time to fully research potential solutions. It collaborated with the university for design knowledge and the federal laboratory for unique additive manufacturing technology to produce the new mold. The manufacturer began production with a manual approach, then added automation technology to increase production rates—more than 40,000/day—and reduce unit cost.

This example demonstrates the value of federal investment, state investment, and the establishment and maintenance of public-private and academic-private sector relationships to synthesize their complementary knowledge to achieve rapid high-impact redeployment.

However, there is a serious gap in manufacturing-relevant higher education. A technical staff member of the national laboratory subsequently argued that "those capabilities should have existed outside a national laboratory."[3] Academic makerspaces can—and should—be used to build the bridge between making and manufacturing, developing the capacity to quickly get to a prototype while considering safety, the role of design on ease of production, cost-effective decision making, and other factors and constraints.

Opportunities

The large number and broad distribution of academic makerspaces create opportunities for collaborative work to support manufacturing and benefit society, consistent with the recommendations of the World Manufacturing Forum. Aspects of university infrastructure are also well aligned with the mission and goals of the Manufacturing USA institutes and their supporting federal agencies, the needs and desires of manufacturing firms and companies, and priorities of regional, state, and federal government. And the pandemic reemphasized both the benefits of and need for collaboration in a highly visible and compelling way.

Many university makerspaces serve the public and may have space that can be used for outreach events held jointly with manufacturing firms. Doing so avoids challenges associated with an industrial setting, such as safety or noise concerns, the need to disrupt regular production, and the possibility of technology leakage.

University-hosted events can also show both what types of educational programs lead to different career options and clever and impactful work that can inspire a wider community. A well-run makerspace reflects an attractive and appealing workplace that welcomes the involvement of others. By cultivating entrepreneurial activities, academic makerspaces become natural hosts or cosponsors of events and may inspire collaboration and even curricular reforms that introduce engineering and other students to policy, supply chain (including resource efficiency), financing, and risk analysis.

Finally, university makerspaces and engineering programs are in a very strong position to explore design for manufacturing. This can be fostered by engaging and collaborating with students and community groups focused on socially oriented products.

[3] Scott Smith, group leader, Machining and Machine Tool Research, Oak Ridge National Laboratory, in personal conversation with JDMC, Feb 4, 2021.

Academic makerspaces are inherently collaborative spaces that can demonstrate the action of business, in this case manufacturing, as an agent of world benefit. As evidenced by covid-19 partnerships, collaborations between the manufacturing and making communities accelerate progress in both domains.

Acknowledgments

The authors are grateful for the critical review of the original draft by Steve Schmid of the University of North Carolina at Charlotte, and both Scott Smith and Lonnie Love of Oak Ridge National Laboratory. Their critique and suggestions led us to sharpen our arguments and emphasize important points.

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