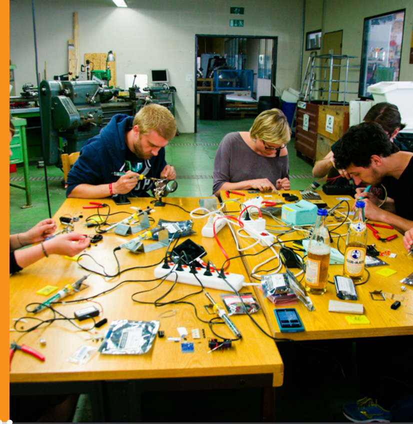

CALIFORNIA COMMUNITY COLLEGES
Doing What MATTERS™
FOR JOBS AND THE ECONOMY

maker space

PROMOTING ENGAGEMENT OF THE **CALIFORNIA COMMUNITY COLLEGES** WITH THE **MAKER SPACE MOVEMENT**

STEM/STEAM SKILLS FOR THE CREATIVE ECONOMY

APRIL 2016

CCST
CALIFORNIA COUNCIL ON SCIENCE & TECHNOLOGY

Promoting Engagement of the California Community Colleges with the Maker Movement

Prepared by the California Council on Science and Technology for the California Community Colleges' Chancellors Office Doing What MATTERS for Jobs and Economy Framework

April 2016

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Acknowledgments

This report has been prepared for the California Council on Science and Technology (CCST) with funding from the California Community Colleges.

ISBN Number: 978-1-930117-81-5

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About CCST

CCST is a non-profit organization established in 1988 at the request of the California State Government and sponsored by the major public and private postsecondary institutions of California and affiliate federal laboratories in conjunction with leading private-sector firms. CCST's mission is to improve science and technology policy and application in California by proposing programs, conducting analyses, and recommending public policies and initiatives that will maintain California's technological leadership and a vigorous economy.

About the California Community Colleges

The California Community Colleges is the largest system of higher education in the nation composed of 72 districts and 113 colleges serving 2.1 million students per year. Under the Doing What MATTERS for Jobs and the Economy framework, the Community colleges supply workforce training, basic skills education and prepare students for transfer to four-year institutions. The Chancellor's Office provides leadership, advocacy and support under the direction of the Board of Governors of the California Community Colleges. For more information about the community colleges, please visit http://californiacommunitycolleges.cccco.edu/.

Note

Any opinions, findings, conclusions, or recommendation expressed in this publication are those of the author(s) and do not necessarily reflect the views of the organizations or agencies that provided support for the project.

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Executive Summary

The Maker Movement is rapidly growing at educational institutions around the world and across age and employment levels, from kindergarten to mid- and late-career. "Making" offers complementary learning environments to the traditional classroom and helps participants develop skills that differ from those developed in traditional student projects and learn-by-doing classes. The spaces housing these activities are called makerspaces, also sometimes referred to as hackerspaces, hacker labs, or fab labs. Broadly, they are all interdisciplinary, participatory, peer-supported learning environments where people can design and invent among a community of other makers. Yet, there is great variation in the capabilities and foci of makerspaces, ranging from traditional crafts such as woodworking to the use of digital technologies such as 3D printers and laser cutters.

There is an inherent challenge in bringing together traditional academic institutions with Maker culture. Traditional academic environments rely on measureable outcomes, working to achieve the "correct" result, and testing to demonstrate the value of an educational experience. In contrast, makerspaces emphasize intrinsic motivation, student-led learning, multiple acceptable products/results, and the process of creating. With this complementary structure, makerspaces are well suited to link colleges with the regional economy and help students be competitive in California's entrepreneurial environment.

In line with the "Doing What MATTERS for Jobs and the Economy" (DWM) framework, the California Community College Chancellor's Office (CCCCO) is interested in growing a statewide network of makerspaces linked to California Community Colleges (CCs) as a key partner in developing a workforce for the innovation economy. At the CCCCO's request, the California Council on Science and Technology (CCST) was commissioned to develop a report to inform these efforts. CCST has conducted a literature review, background research, and interviews to develop a playbook of considerations and recommendations for establishing a network of makerspaces.

In order to preserve the spirit and value of Making while meeting the needs of the community colleges to demonstrate efficacy, the CCs will need to bring in alternative metrics for evaluating outcomes. These could include the following:

- Human-scored rubrics, such as observations by trained participants of behaviors and skill sets, instead of multiple-choice tests to evaluate process and exercised skills over product achieved.
- Informal written communication of a Maker project to an audience of peers, as opposed to turning in a project for grading by a teacher; in this way, the emphasis is placed on the skills of communication, collaboration, and self-reflection.
- Credentials, badges, and certifications to complement transcript-credit classes.
- Amount of student engagement, as shown through the use of space, attendance at events, and documented projects.

- Instructional alignment/integration, including new curriculum and pedagogy, laboratory sharing across divisions and/or departments, coordination of student projects between the makerspace and classroom, and engagement of advisory committees through events or meetings.
- Extent of partnerships and leveraged support (cash and in-kind) established with key economic and workforce stakeholders; these may include financial institutions, government, economic development agencies, workforce investment boards, community-based organizations, foundations, and business/industry.
- Number of business licenses, patents and copyrights filed, private equity obtained, self-reported jobs created by affiliated students, faculty, community members, and businesses.

To build on the growing momentum, the CCCCO DWM framework will be issuing a request for proposals with a total of $10 million available to establish a 10-campus network of makerspaces linked to community college campuses around the state by December 2017. These costs would cover startup and three-year operations for 10 makerspaces, associated work-based learning opportunities, and a system of network support, including paid staff time to support the network, an annual conference to bring together leaders, and regular communications across spaces. Cost estimates are detailed in Chapter 3 and broadly based on information from Danny Beesley and Gina Lujan gathered on the startup and first year costs at the Laney College Fab Lab and Sierra College Hacker Lab, respectively.

The envisioned makerspace network would encompass member institutions and a lead institution to run an advisory panel and evaluation component. Network activities should ideally include regular, perhaps quarterly, web conferences and an annual in-person meeting. Additional suggested activities for network participants include:

- Site visits to independent Maker/Hacker spaces.
- Participation in the U.S. National Fab Lab Network (http://usfln.org), MakerCon Bay Area (http://makercon.com), and Maker Faires (http://makerfaire.com).
- Affiliation with the National Association for Community College Entrepreneurship (NACCE), International Business Innovation Association (InBIA, formerly the National Business Incubation Association, NBIA), and MakeSchools.org (http://make.xsead.cmu.edu)
- Organization of professional development events and facilitation of networking opportunities to build capacity (for example, the Making Across the Curriculum course development at Folsom Lake College and NACCE's collaborative project with the Appalachian Regional Commission (ARC) to map entrepreneurial ecosystems and help colleges build out their entrepreneurial programming).
- Investigating the potential for collaborations with 4-year and doctoral degree granting institutions and federally funded laboratories to develop mechanisms for the network to have access to specialized high-tech facilities and tools.

The advantages to having a coordinated network of makerspaces include the ability to pool resources, such as staff time to write funding proposals, pool buying power, and share wisdom on how to establish and run a makerspace. Network collaboration will also help campuses build on existing workforce and internship structures to develop makerspace-facilitated work-based learning (WBL)/internship programs with local businesses and industry.

Grant proposals for participation in the CC makerspace network could be solicited in three categories: 1) establishing a makerspace, 2) growing a makerspace, and 3) becoming the lead institution for the network. The typical costs of establishing and running a makerspace, including establishment of a WBL component, may include the following:

- To plan a makerspace:
    - Community assessment of local assets and needs
    - Core/founding college workgroup of faculty, administrators, and staff to plan and develop across divisions
    - Community outreach events, such as meetups, speaker series workshops, and other events to strengthen and build the entrepreneurial ecosystem
    - Partnership development through creating agreements, memorandums of understanding (MOUs), and/or working relationships with key stakeholders and leaders from local governments, other makerspaces, foundations, banks, etc.
- To set up a makerspace, the following must be addressed:
    - Rent/lease space
    - Staff, faculty, and administration engagement
    - IT support
    - Marketing
    - Infrastructure and utilities
    - Supplies and software
    - Event support to fund speaker panels, start up competitions, business plan competitions, hackathons
    - Trainers/facilitators hired on for short-term instruction, as for skill instruction in coding, laser cutting, industrial sewing, etc.
- To plan the internship/WBL component, the planning grant should address actions needed to secure 100 internships per campus, such as:
    - Mapping resources based on the needs and interest of students and regional opportunities
    - Outreach to potential employers in local businesses and industry to build relationships and develop training partnerships
    - Back end infrastructure to manage internship payroll (see Foundation for California Community Colleges' LaunchPath web function)
    - Development of assessment tools (e.g. skills gained, certificates earned, projects produced, etc.)

The CCCCO can help pave the way for the development and sustained support of makerspaces by classifying them as a campus resource, similar to libraries and computer labs. Though the setup for individual makerspaces will vary depending on local assessments, the CCCCO can help facilitate network communications and collaboration among institutions and other stakeholders. By developing relationships with industry and research laboratories, the CC-makerspaces could establish opportunities, such as resource-sharing agreements and internship programs, for users beyond the CC network. In these ways, the CC-makerspace network can achieve a number of key goals: helping users build 21st century and soft skill sets, including communication, critical thinking, collaboration, and creativity; providing students, faculty, and other users with opportunities to engage with local and regional industry; and helping the CCs establish themselves as key stakeholders in the entrepreneurial workforce.

Chapter 1. Introduction

Purpose and Process

The California Council on Science and Technology (CCST) was commissioned by the California Community Colleges Chancellor's Office Workforce & Economic Development Division to develop this report. The purpose of the paper is to provide a background on the Maker movement and inform the creation a network of community colleges connected to makerspaces. The overall goals of this connection are to complement student learning environments in ways that foster 21st century skills and position community colleges as key stakeholders in their regional entrepreneurial economies.

Development of the report included a literature research review, a series of surveys and interviews with people engaged in a variety of makerspace settings, and a broad review from experts in the Maker movement, workforce development, as well as research and education institutions in California. There are many complex issues to consider when developing both individual makerspaces and a network of community college-linked spaces; this paper serves as an initial "playbook" to facilitate these important efforts.

What Is Making?

Simply put, making is making things.

So why is there so much excitement, and an entire movement around making? After all, people have always been making things – the mechanic in her shop, the jewelry maker at his table, the chemist in her lab – they all make things.

There are a few hallmarks of *making* as part of the new phenomena of Maker culture, however, that make it distinct:

1. It is **communal** – emphasizes shared makerspaces, Maker faires, online Maker communities, and other opportunities to communicate and cooperate.
2. It is **empowering** – encourages people to expand their abilities.
3. It is **interdisciplinary** – encourages collaboration among people with different skill sets, and development of skill sets in different fields.
4. It is **diverse** – purposefully mixes students, businesses, community members across the Science, Technology, Engineering, Art, and Mathematics (STEAM) spectrum.
5. It embraces **making as a process** and a personal identity no matter what the field – as opposed to focusing on one field by learning how to be a computer programmer, or a cook, or a robotics expert, or a bio-engineer.

6. Making often has a **STEM/STEAM** and, at least for adults, an **entrepreneurial focus**; however, the interdisciplinary nature of making means that makers also engage in activities that may not clearly fall into the STEAM or entrepreneurial categories.
7. It is a form of **open-ended, inquiry-based learning**.
8. It's **creative, fun, and playful.**

> *The (maker) movement is unified by a shared commitment to open exploration, intrinsic interest, and creative ideas. And it's spreading: Online maker communities, physical makerspaces, and Maker Faires are popping up all over the world and continually increasing in size and participation. Moreover, there is a growing national recognition of the maker movement's potential to transform how and what people learn in STEM and arts disciplines.*
> - Peppler & Bender (2013)

What is a Makerspace?

Makerspaces are places where people can design and invent among a community of other makers.

In this document, we use makerspace as a generic term that includes a variety of monikers. Davee, Regalia, and Chang, in a survey of 51 sites found 45 different names for the spaces. Two terms in particular that are often associated with makerspaces are Fab Labs and hackerspaces. According to the authors of the survey, "Fab Labs are spaces that commonly share a core set of digital fabrication and prototyping tools, for example, laser cutters, vinyl cutters, CNC routers, and 3D printers. Founded at MIT's center for Bits and Atoms by Neil Gershenfeld, the Fab Lab network is supported by the Fab Foundation and by FabEd, which is specifically geared toward supporting educational institutions. Hackerspaces are largely associated with adult, computationally focused making (Cavalcanti, 2013). Thus, both hackerspaces and Fab Labs emphasize forms of making that utilize digital technology."

Impact of the Maker Movement

The Maker movement is affecting businesses, research and four-year universities, community colleges and secondary institutions across the country and around the world. In a joint letter to President Obama, over 150 U.S. institutions of higher learning pledged commitments to expand opportunities to Make (Executive Office of the President, 2014). The commitments ranged from accepting Maker Portfolios in the admissions process, investing in makerspaces, and participating in regional networks of community organizations supporting the Maker Movement. In response, the White House Office of Science and Technology Policy (OSTP) has made a Maker Education Initiative part of its agenda for improving STEM education. In June 2014, President Obama hosted the first ever White House Maker Faire, and in line with the one-year anniversary, celebrated a National Week of Making in June 2015 along with federal agencies and the broader community.

What Learning Outcomes are Achieved in a Makerspace?

Making and makerspaces are complementary to curriculum driven classes. Both are necessary; one cannot have a surgeon or a pilot learning solely by making. Making involves what are often described as "the 4 C's" of necessary 21^{st} century skills:

- Creative thinking
- Critical thinking
- Collaboration
- Communication

In fact, the Maker Movement is a "shared knowledge community" – while equipment is an essential part of many makerspaces, it is the connections to people from a variety of disciplines and others worldwide which make the makerspace environment uniquely supportive.

Creativity is central to making, as is experimentation. Because the work is hands-on, and because the focus is more on a supportive process than an end result, participants can engage in a cycle of trying and failing – failing being a necessary component of risk-taking and innovation. Making relies on intrinsic motivators, rather than extrinsic ones; makers set their own agendas, their own project goals, and their own metrics for success, to an extent. It emphasizes collaboration both at the local and the virtual level. Through the process, participants practice and acquire tangible skills, such as the use of software and equipment, that are useful in regional industries. Thus, making is also a form of self-directed workforce training.

Why Should Community Colleges Engage with the Maker Movement?

Engaging with a makerspace during their time at a Community College (CC) can mean that students have developed skills they would not have otherwise gained. Specifically, this includes 21^{st} century learning skills (creative thinking, critical thinking, collaboration, communication), 21^{st} century literacy skills (technology literacy), and 21^{st} century life skills (flexibility, initiative, social skills, productivity), as well as problem solving abilities, which are key skill sets for entrepreneurs, small business employees, and those in the STEM/STEAM economy.

Engaging students to pursue degrees and careers in STEM fields can have life-long impacts. As shown in the chart below, according to data from Tony Carnevale and Nicole Smith of the Georgetown Center on Education and the Workforce, adults aged 21-54 with STEM bachelors degrees have earned 10-30% higher mean income than those with non-STEM degrees over the past nearly 50 years.

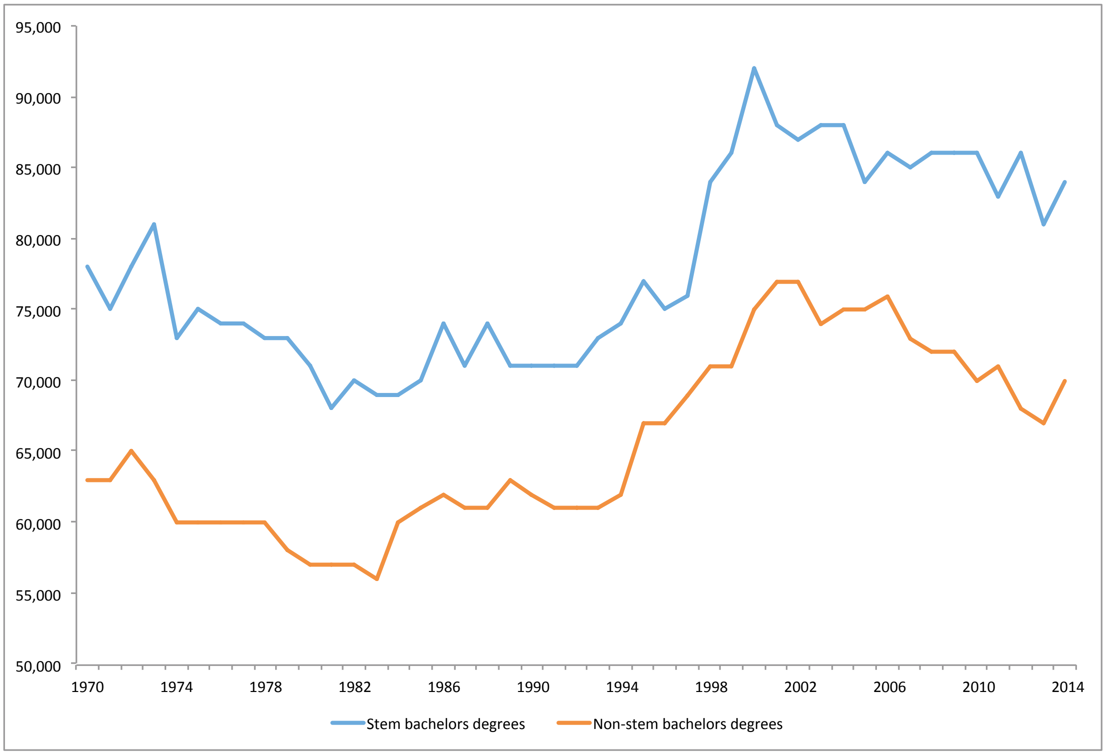

Figure 1.1. Mean earnings for STEM versus non-STEM bachelor's degree holders from 1970 to 2014. (Source: University Ventures Letters, Volume VI, #5. March 4, 2016. http://universityventures.com/publications.php?title=long-road-out-of-olive-garden-of-eden)

In 2004, California Assembly Bill 1417 (Chapter 581, Statutes of 2004) triggered the creation of a performance measurement system for the California Community Colleges. The legislation and the ensuing budget action authorized the California Community Colleges Chancellor's Office (CCCCO) to design and implement a measurement system containing performance indicators for the system and its colleges. The comprehensive system is known as Accountability Reporting for the Community Colleges, or ARCC, whose purpose is to provide stakeholders with clear and concise information on key student progress and success metrics to improve performance.

In 2011, pursuant to Senate Bill 1143 (Chapter 409, Statutes of 2010), the Student Success Task Force (SSTF) was formed, including a diverse 20-member group of CC leaders, faculty, students, researchers, staff, and other external stakeholders, to delve into college and system-level policies and practices with the goal of identifying best practices and statewide strategies to promote student success. The SSTF recognized student Momentum Points towards student success.
The accountability for, and measurement of, grant activities administered through CCCCO's Workforce and Economic Development Division under the Doing What MATTERS for Jobs and Economy framework recognizes these student Momentum Points (and Leading Indicators thereof) in its menu of common metrics for all grants.

Within the menu of Leading Indicators and Momentum Points lie the opportunities for makerspaces to align with the SSTF student success scorecard. Here we highlight those leading indicators and momentum points where makerspaces, if appropriately implemented, can realize alignment outcomes and student development goals.

Leading Indicators (LI) of Curriculum Alignment to Labor Market Needs
LI 1. Alignment of skillsets within a program (or set of courses) to a particular occupation and the needs of the labor market.
Student Momentum Points (MP)
MP 19. Completed a work readiness soft skills training program.
MP 27. Participated in a college internship or workplace-learning program within a Career Technical Education (CTE) pathway.
MP 29. Acquired an industry-recognized, third-party credential.

Community colleges can use the establishment of a makerspace as a means to position themselves as a key stakeholder in their region's innovation economy. They are ideally situated at the crossroads of higher education and workforce development to benefit from the various opportunities that makerspaces have to offer students across campus and across CTE and STEM/STEAM pathways. For example, makerspaces can help CCs align their curriculum to regionally important occupations and potentially offer industry or employer-recognized certification. They also offer additional pathways for community college students to achieve the aforementioned momentum points. Furthermore, a network of CC-linked makerspaces would place a strong emphasis on hands-on, inquiry based learning, including working directly with STEM/STEAM professionals through internships and participatory field experiences.

There are already many institutions of higher education in California that have established makerspaces of one sort or another, including numerous community colleges. The Maker Movement is on the cusp of widespread impact in the higher education system. It is a propitious time for the Community College System to consider a global strategy for effectively integrating makerspaces into its educational and workforce preparation goals. In this paper, we provide an overview of the history and development of the Maker Movement and a vision for growing a maker network across the California Community College System.

Chapter 2. Literature Review

Evolution of the Makerspace

The notion of fostering hands-on innovation through a collaborative workspace that offers support in the form of equipment and/or expertise is not new, and has been implemented with varying degrees of success by tech pioneers such as Edison and Bell back in the 19th century. But the makerspace of today is different in two critical ways. First, it is a model intended to be copied and replicated: the makerspace movement is a flexible paradigm that is taking root in a variety of institutions. Second, it is a movement at the intersection of innovation and education; a primary outcome for many makerspaces is not the innovative products designed or business models launched, but the skills and experience gained by the participants as part of a hands-on learning experience not available elsewhere.

Defining a Makerspace

The makerspace movement as it exists today is about ten years old, coalescing into a concrete phenomenon when MAKE Magazine was launched in 2005 and coined the term 'makerspace'. It grew from the somewhat earlier community of 'hackerspaces', essentially collections of programmers sharing a physical space. The hackerspace movement began in Europe around 1995 (Cavalcanti, 2013). Although today the terms hackerspace and makerspace are sometimes used interchangeably – especially by people in the hackerspace movement – the founders of the makerspace movement consciously sought to differentiate themselves with different types of craft spaces structured along the lines of traditional businesses instead of the democratic collective models commonly used by hackerspaces. According to Cavalcanti, founder of the Artisan's Asylum makerspace, "In my mind, hackerspaces largely focused on repurposing hardware, working on electronic components, and programming… Makerspaces became associated with a drive to enable as many crafts to the most significant extent possible."

The rise of the makerspace resulted from a 'perfect storm' of digital design, rapid prototyping, and social networking (Fixson and Marion, 2014). In particular, rapid prototyping technologies have progressed to the point where 3D-printing machines can allow the fabrication of almost any part in a batch size of one (Lipson and Kurman, 2013; Petrick and Simpson, 2013). This has opened up small batch production which was previously economically impossible. In combination with a vastly increased ability to network with other people and share information on an unprecedented scale, it's become possible for almost everyone to engage in product development processes as a designer.

The sense of community has been a hallmark and key component of the Maker Movement from the beginning. Much of the movement's sense of identity stems from the inception of Make Magazine in 2005 (http://makezine.com) and the follow-up Maker Faire in 2006. This in turn has led to broader multiplatform social tools through the Maker Media website (https://makermedia.com).

Another key element to makerspaces has been a rapidly increasing array of fabrication tools. Whereas developing a physical prototype of a new device or product was traditionally an expensive and time-consuming process, devices capable of producing relatively inexpensive individual 3D models have been available to consumers since around 2011. In the past few years 3D printers using technologies such as stereolithography, filament deposition manufacturing, and fused filament manufacturing have become available from dozens of manufacturers offering a wide range of choices at increasingly lower prices. Makerspaces today can choose from a steadily increasing collection of ever-more capable and affordable prototyping tools.

In addition to 3D printing machines, most makerspaces include a range of other tools, including basic electronics equipment (including affordable, simple-to-program circuit boards such as the Arduino Board), a laser cutter, a vinyl cutter, a computer numerical control (CNC) router, a CNC milling machine, and more. Equipment varies depending on the organization behind the makerspace. Techshop (http://techshop.ws) and FabLab (http://fab.cba.mit.edu/about/faq/), for example, are franchises that each include standardized equipment and resources. TechShop is a chain of for-profit spaces started in 2006 that calls itself “America’s First Nationwide Open-Access Public Workshop”. FabLabs are a network of spaces started in MIT’s Media Lab around 2005, which have specific space requirements and standardized tools, software, and curricula.

Because of the variety of creative endeavors and types of places where making happens, there is an increasingly broad range of makerspace parameters. A recent survey of 51 youth-serving organizations self-identified as makerspaces revealed no less than 45 different names and descriptions of the programs (Davee, Regalia, and Chang, 2015).

How They’re Run: Legal Status and Governance

The potential of the makerspace has caught the attention of multiple sectors. Essentially collaborative in nature, most of them exist at the intersection of two or more spheres of influence. While makerspaces are open-source in nature and rely on sharing and collaboration, and prototyping equipment is more affordable than ever, the spaces nonetheless constitute an investment in space and resources, and are created with different outcomes in mind.

Manifestations of the ‘Maker Movement’ might be grouped into three primary categories: as a focus for entrepreneurial and/or community creativity; as a focus for workforce development (in particular for the STEM pipeline); and as a focus for inquiry-based education (Vossoughi and Bevan, 2013). These categories are non-exclusive and in many instances overlap.

This is the primary reason why, although makerspaces began as a learning force in the nonacademic community, institutions of higher education have been enthusiastic adopters of the makerspace format. One assessment of the underlying philosophy behind educational makerspaces asserts that they have the potential to “revolutionize the way we approach teaching and learning” (Kurti, Kurti and Fleming, 2014). Maker-related education inspires deeper learning, involves a greater degree of student ownership, and is consistent with the inquiry-based learning approach that has been a focus of science education standards since 1995 (NRC, 2000).

There is also significant investment by the private sector in makerspaces. TechShop, which manages a network of membership-based workshop and fabrication studios, is a private company that was named one of America’s fastest growing companies in 2013 by Inc. Magazine. Access to the equipment is fee-based. Private industry and communities alike are coming to consider makerspaces sound investments; the City of East Lansing, for example, sought to support its “entrepreneurial ecosystem” through the exploration of and investment in makerspaces, as part of a broader strategy in Michigan to place technology, innovation, and entrepreneurship at the center of economic partnership (Benton et al., 2013). This would result in a public-private partnership that would leverage both maker movements at the university and the public library.

No matter how a makerspace is run, each shares a broad commitment to the notion of providing equipment, support, and space for people to make things. The intended outcomes do not differ so much as the emphasis on the rationale for the makerspace, whether educational or as part of a broader economic strategy. One key difference is the degree of accessibility that the various makerspaces offer. Those affiliated with Institutes of Higher Education (IHEs) are generally restricted to university-affiliated users; private members-only programs are available if users are able to pay the associated fees.

There has been some concern in the maker community about whether and how funding sources may impact the makerspace experience or outcomes. In 2012 there was some controversy when it was learned that MAKE Magazine had received an education award from the Defense Advanced Research Projects Agency (DARPA) within the U.S. Department of Defense. This led to speculation in the makerspace community that DARPA would obtain ownership of the software or other work developed by participants in the Maker Faire. Maker Media founder Dale Dougherty assured the community that this was not the case (Dougherty, 2012), but the concern remains that government or institutional support of any kind may come with strings attached.

Studies About the Maker Movement

Because the maker movement is relatively new, much of the literature about the movement has focused on defining what a makerspace entails, sometimes in specific settings and often citing examples of different types. There is an extensive second category of literature that focuses on how makerspaces integrate with a particular practical and/or philosophical approach, and whether and how to implement a makerspace in different specific settings.

Maker Media is at the forefront of the effort to define the maker movement and quantify its impact; its 2014 overview of the Maker Impact Summit (Deloitte Center for the Edge) held in December 2013 provides perspectives and experiences from many participants, along with statistics on the number of makerspaces created, funds raised through ventures such as Kickstarter in 2014, etc. to provide a sense of scale for the scope of the movement. In the aggregate, these numbers appear to support the case that makerspaces are likely having a significant economic impact, although most of the indicators are indirect. For example, the Maker Media report cites total 2013 sales of merchandise on the ecommerce site ETSY as an indication of the power of collaborative production. While ETSY is a very likely sales outlet for small entrepreneurs who develop products in a makerspace, it has no explicit connection to the makerspace movement and there is no way at present to determine the percentage of its sales/products that were developed with the involvement of a makerspace.

The Maker Media report also provides an overview of the "Maker ecosystem." This visualization (Figure 2.1) includes programs that participated in the Maker Faire as well as other organizational components of the system.

Figure 2.1. Representative players in the Maker ecosystem. (Deloitte Center for the Edge, 2014)

Although the categorization of these organizations is somewhat arbitrary – Kickstarter, for example, can be considered a marketplace in certain circumstances, in addition to a financing option – it is a useful way of understanding the way Maker Media itself perceives the movement. The spectrum of organizations in Figure 2.1 is aligned along an outcome-oriented model, with bringing a product to market as the end result. While the overview is explicitly inclusive of programs offering every sort of service, the visual progression nonetheless suggests that the ultimate goal is entrepreneurial and that most programs provide support for a specific step or range of steps along the progression to this goal. It is not a coincidence, for example, that Maker Media programs – Maker Faire and Make: Magazine ("Inspiration and Learning" category), and the Maker Map and Maker's Row ("Connectors" category) – provide services which span the full spectrum of this makerspace ecosystem.

Maker Ed provides an alternative functional approach to categorizing makerspaces (Davee, Regalia, and Chang, 2015). Maker Ed is a nonprofit organization founded in 2012 as a response to the White House Educate to Innovate Initiative (White House Office of the Press Secretary, 2009). With a greater focus on STEM education and the K-12 education system, Maker Ed's overview revealed three broad categories of makerspace: **dedicated**, **distributed**, and **mobile**. Dedicated makerspaces concentrate equipment, tools, and materials in a single space. These tend to concentrate on those forms of making which require greater safety precautions, ventilation, and dust control, such as metalworking. Distributed makerspaces are found in many places within an organization. These tend to focus on IT related programs and makerspaces targeted at younger students; often, there is a centralized location offering greater support and/or more extensive equipment (such as the use of 3D printers). Mobile makerspaces consist of tools and materials designed to be transported to different locations, either within a single facility (through the use of mobile tool cabinets, for example) or between locations (on a truck or van, for example). In either case, these serve primarily as ways to seed creativity rather than offer sustained support.

These functional categories may serve any one or more of the three primary trends of entrepreneurial/community creativity; workforce development, and inquiry-based education identified by Vossoughi and Bevan. They represent efforts on the part of a variety of institutions and settings to apply the wide-ranging promise of the makerspace movement to different scenarios.

While there exists a wide range of literature describing the practical aspects of implementing a makerspace, and the degree to which the maker movement has the potential to transform education, mainstream makerspace-related literature nonetheless tends to remain focused on relatively narrow questions, which some scholars have criticized. Martin (2015) asserts that while many makerspaces are eager to incorporate digital tools, the equally essential makerspace components of community infrastructure and Maker mindsets are often overlooked. "An explicit emphasis on the tripartite nature of making is necessary because of the pervasive desire in education for silver bullets that can solve big problems through simple means," Martin notes.

Likewise, research on educational applications of making tends to focus on middle and high school students, with less focus on younger children (Brahms & Crowley, In Press; Gutierrez et al., 2014). There is also limited information on makerspace sustainability and investment models. One assessment of a series of makerspace grants provided by Cognizant Technology Solutions indicated that investments had different roles depending on the organization receiving the funding, but noted that one-year grants are likely insufficient to allow new or start-up organizations to figure out a viable business model and achieve funding sustainability (Dorph and Cannady, 2014).

Makerspaces in Institutions of Higher Education

A 2014 survey of the top 127 US undergraduate institutions as ranked by US News & World Report found makerspaces at 35 of them (Barrett et al., 2015); two institutions had multiple makerspaces. The majority of these makerspaces were housed in a university department and open only to people at the university. A variety of staffing models were employed, with most programs using a mixture of faculty and/or students and/or dedicated support staff (Figure 2.2).

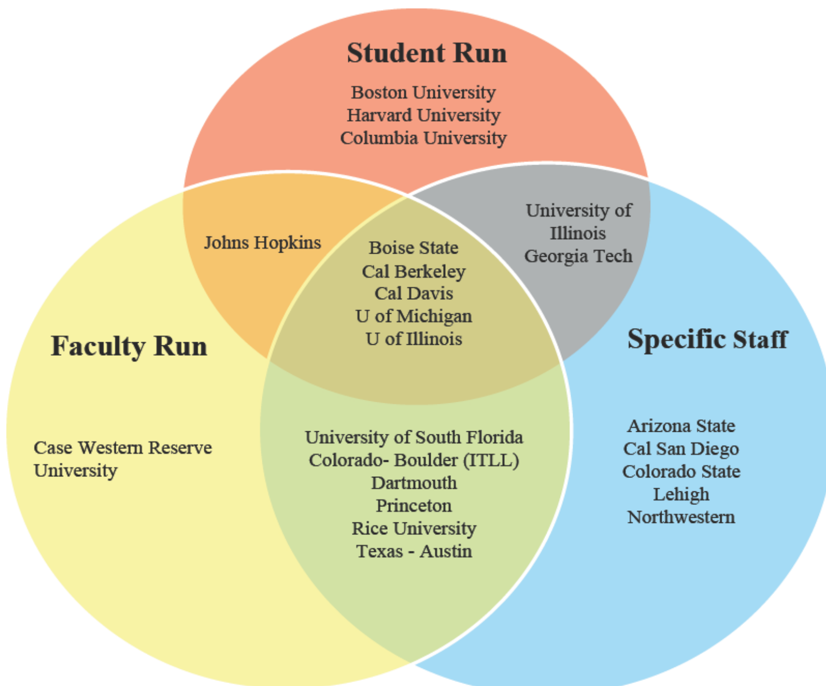

Figure 2.2. Venn diagram showing identified operational models for makerspace management (Barrett et al.). NB: Cal San Diego (UC San Diego) characterizes their space as run by both faculty and specific staff at this time.

A distinguishing feature of many university programs is their “bottom-up” development, as opposed to a government-funded, “top-down” design approach (Forest et al., 2014). An example of the latter is the Manufacturing Engineering Education Partnership (MEEP) Learning Factory, a curriculum model developed in collaboration with three universities, the Sandia National Laboratories, and a variety of industry partners, and supported by $2.8 million provided by the National Science Foundation (NSF) and DARPA. MEEP was designed specifically to enhance the STEM pipeline. While MEEP was successful in meeting many of its goals, as Forest et al. point out, the makerspace Invention Studio at Georgia Tech is achieving many of the same outcomes as the Learning Factory without any reliance on grant funding, simply by leveraging facilities obtained for a specific series of design courses and giving students responsibility for daily operation, maintenance, and equipment training for newcomers. The Invention Studio is more sustainable, engages students, and is already tailored to student and faculty interests on campus – in contrast, the Learning Factory model needs to be adapted for each implementation.

In fact, it could be argued that programs which develop from, and are dependent to some extent upon, greater participation by students and other members of the community succeed in part because the nature of this setup requires embracing the tenets of an effective knowledge building community (Martin, 2015). The ways in which educational institutions have incorporated computers in the classroom historically is a cautionary parallel; although researchers have long argued that the social architecture of activities surrounding technology is just as important as the technology itself, policy documents often assume "that the computers themselves are the real agents of change, and placing them in classrooms will catalyze… shifts in teaching and learning" (Mercier, Higgins, and Joyce-Gibbons, 2014). However, universities are recognizing that there is more to enabling a makerspace than equipping a space with a 3D printer and machine tools.

There are numerous programs at the community college level as well, although there is less research available about them. A 2015 CCST survey identified at least 17 makerspaces hosted or co-managed by community colleges, five of which are in California. One of these even includes a 'Maker Certificate Program' designed to train people to lead maker activities (Sonoma State University, http://www.thestartupclassroom.org/maker-course/). Nationwide, the United States Fab Lab Network has a strong focus on community colleges, with at least 29 listed community college members among the 56 Fab Labs in its network (http://usfln.org). The Fab Lab model is attractive to many community colleges because it provides a core charter, a blueprint for a common set of tools and processes (although not all Fab Labs are required to have the same equipment), and access to (required participation in) a global knowledge sharing community. It also provides a comprehensive sample budget for the first three years.

The Entrepreneurial/Educational Interface

The potential of makerspaces as a component of the STEM innovation pipeline has driven considerable interest on the part of the high-tech sector, spurring grants such as the Cognizant Making the Future initiative (2013) which invested in 25 makerspace programs around the country. Makerspaces are attractive because they address many essential components of the entrepreneurial ecosystem (Figure 2.3).

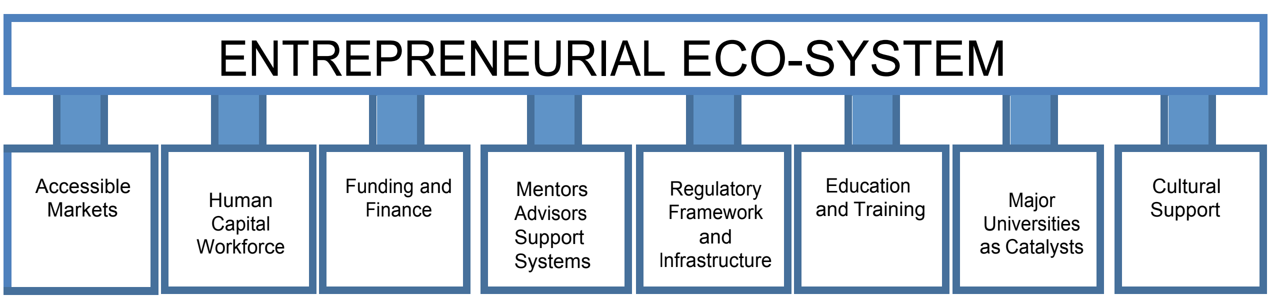

Figure 2.3. Pillars of the entrepreneurial ecosystem. (World Economic Forum [WEF], 2013)

Makerspaces are designed to foster inquiry-based "play" in a knowledge-sharing setting that offers support in experimentation, design, and implementation. In this regard they support development of technical talent (human capital), a support system that includes mentoring, entrepreneur-specific training and (frequently) alignment with educational curricula, a culture of respect for entrepreneurship (one of the catalytic benefits of a major university), and a cultural support network that is tolerant of risk and failure. If one counts the broader range of services included in the makerspace ecosystem as defined by Maker Media (Figure 2.1, above) – which includes access to markets, financing opportunities, and assistance with infrastructure – then makerspaces address virtually every pillar as defined by the 2013 WEF survey.

The most critical component of the makerspace environment from an entrepreneurial standpoint may, in fact, be the "maker mindset" which is sometimes overlooked or neglected as a component of a makerspace (Martin, 2015). Of the eight pillars identified by over 1,000 entrepreneurs surveyed by the World Economic Forum, the one most lacking around the world was cultural support. Cultural support, including tolerance of risk and failure, celebration of innovation, and a positive image of entrepreneurship – all of which are part of the maker mindset – was ranked as the least prevalent pillar; just 41% of respondents worldwide said cultural support was available, and when the US is excluded from the response pool, the total was only 31% (WEF 2013, exhibit 2-1).

From an educational perspective, there has been significant interest in aligning the maker movement with educational approaches of various institutions (e.g. Peppler and Bender, 2013; Kurti, Kurti, and Fleming, 2014; Martin, 2015). Because interest in making as an educational activity is new, empirical evidence specifically about its pedagogical value is still limited. However, it has been argued that the making movement is well aligned with the standards set forth in the new Framework for K-12 Science Education (National Research Council, 2011). In particular, the inclusion of "defining problems" and "designing solutions" as core engineering practices in the science curriculum are clear points of alignment with makerspace activities (Quinn and Bell, 2013).

However, makerspaces are also ideal settings for work-based learning, part of an approach which seeks to connect classroom learning with real-world applications in order to better prepare students for both higher education and the workplace (Rogers-Chapman and Darling-Hammond, 2013). Studies have shown that work-based learning programs improve student completion rates, increase student interest in potential career paths, and develop critical workplace skills such as creative problem solving and teamwork. A key component to successful work-based learning programs is the use of performance-based or mastery learning assessments which allow students to demonstrate deep learning of skills on an ongoing basis, providing students with multiple opportunities to demonstrate mastery and allowing more room for experimentation and failure.

Work-based learning is the centerpiece of multi-state initiatives such as the Pathways to Prosperity Network. The Network was created by the Harvard School of Education and Bostonbased nonprofit Jobs for the Future in 2012 and currently consists of eight participating states, including California (Pathways to Prosperity Network, 2014). In California, the Career Pathways Trust (CCPT) made $250 million available in 2014 for “linked learning” programs and another $250 million in 2015. While makerspaces are not a specifically named component of this program, they align with the priorities of the CCPT, and it is likely that some of the grant recipients (including 167 school districts, 85 community colleges, and 20 universities) used this funding for makerspace related activities (California Department of Education, 2014).

Despite these positive alignments with aspects of the innovation ecosystem, however, makerspaces still do not generally factor into innovation rankings because their impact remains hard to quantify. They are not mentioned in the most recent Global Innovation Index, Bloomberg Innovation Index, or the long-running Index of the Massachusetts Innovation Economy.

The White House Initiative

A significant boost was given to the Maker Movement when the White House held its first Maker Faire in 2014 (Executive Office of the President, 2014). In part at the behest of a joint letter from over 150 institutions, many of which made specific commitments to invest in makerspaces directly or expand existing facility access to makers, the President’s Maker Education Initiative calls for the creation of more makerspaces, increasing the number of projects, and producing more mentors.

The initiative is part of the agenda of the Office of Science and Technology Policy (OSTP). Specifically, the Maker Education Initiative falls under the category of OSTP’s efforts to improve STEM education. In addition, it builds upon the Young Makers Program (http://youngmakers.org), which has developed a playbook to help parents, teachers, and cities start local Maker clubs. Consequently, the Maker Education Initiative, while not exclusive to K-12, predominantly focuses on younger students and less on work-based programs or programs in institutions of higher education. Ideally, community college Maker facilities can be accessed by high school partners for joint programming.

Metrics for Success

There are multiple ways one can look at the success of the Maker Movement: on the macro level and the micro (individual programs) level, and in the context of the makerspace categories proposed by Vossoughi and Bevan (entrepreneurial, workforce training, or STEM education). Globally, assessing the impact of the Maker Movement is challenging due to its relatively recent inception, its decentralized dissemination, and the wide variation in facilities, equipment, and underlying goals/educational philosophies of the respective makerspaces. Maker Media and Deloitte Center for the Edge, which are in many ways at the epicenter of the movement, considered in their overview of 2014 that the potential impacts of the Maker Movement are "far from certain." Makerspaces may align with many pillars of the entrepreneurial ecosystem as measured by the WEF, but identifying alignment is different from applying a specific metric for success to any given makerspace or network of makerspaces.

The presence of makerspaces can be included in measures of entrepreneurial ecosystem vibrancy proposed by Stangler and Bell-Masterson (2015). They suggest four indicators: density, fluidity, connectivity, and diversity. Makerspaces align best with the connectivity metric, which assesses program connectivity, spinoff rate, and dealmaker networks; however, these metrics will require analysis over time.

In the context of an institution of higher education, makerspaces also align well with the P21 Framework (http://p21.org), developed in collaboration with a network of states that includes California in order to help practitioners integrate skills into the teaching of key academic subjects (Figure 2.4). Makerspaces address every element of the framework – life and career skills, critical thinking, collaboration, and technology skills, in addition to entrepreneurial literacy. In this context, the assessment of 21st century skills proposed as part of the framework (2015) may be a suitable framework for designing ways to assess makerspaces in an academic setting:

- Supports a balance of assessments, including effective, formative and summative assessments;
- Emphasizes useful feedback on student performance embedded into everyday learning;
- Requires a balance of technology-enhanced, formative and summative assessments;
- Enables development of portfolios of student work that demonstrate mastery of skills; and
- Enables a balanced portfolio of measures.

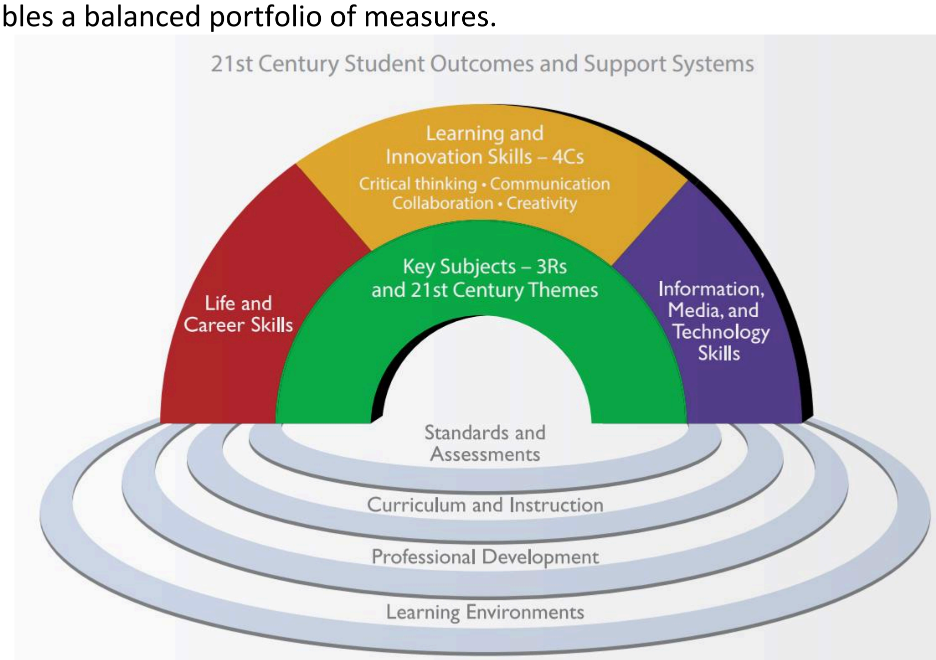

Figure 2.4. P21 Framework for 21st Century Learning. (P21, 2015)

This model may be enhanced by incorporating it as a component of the broader logic model used by Cognizant in its Making the Future Initiative (Dorph and Cannady, 2014; Figure 2.5, below).

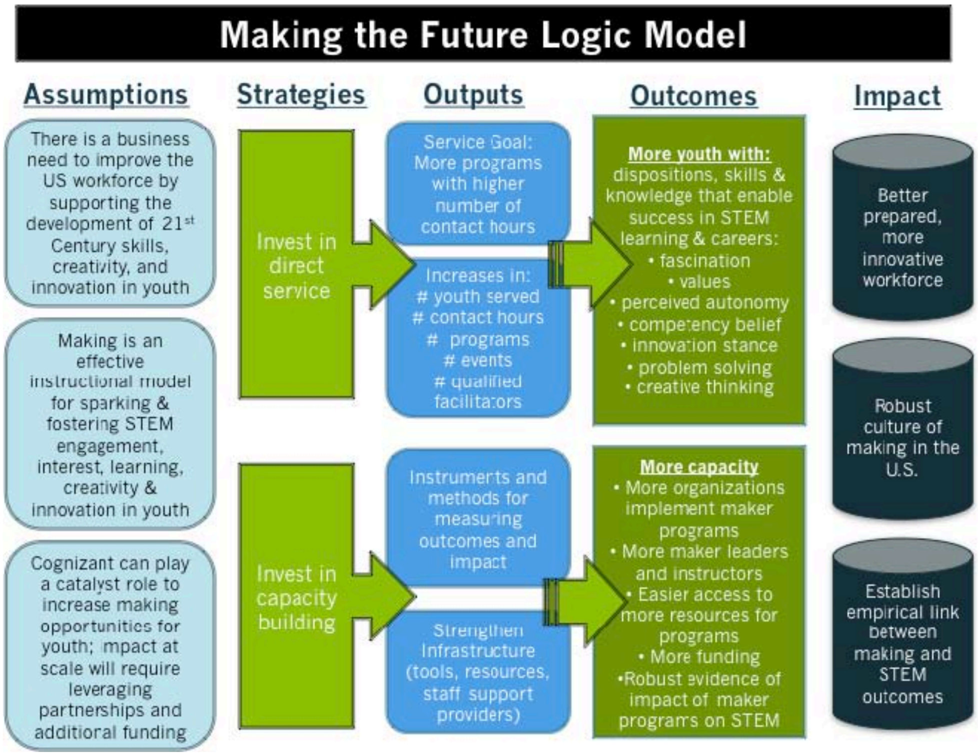

Figure 2.5. Logic model for Cognizant's Making the Future Initiative. (Dorph and Cannady, 2014).

In this model, outcomes from the P21 framework would correspond to the "empirical link between making and STEM outcomes" (bottom right of figure). While assessing what constitutes a "robust culture of making" might prove challenging, the "innovative workforce" is something that can be quantified in numerous ways. For institutions such as the community college system, which are already closely tied to regional workforce development, the establishment of makerspaces could then be a way both to align curricula with the P21 framework and to position themselves as key stakeholders in their respective regions' economies.

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CHAPTER 3. A Playbook for Growing a Maker Network Across the California Community College System: Developing a Strong Workforce for California's Innovation Economy

Vision: Statewide Network of Makerspaces Linked to Community Colleges

The California Community College Chancellor's Office (CCCCO) Doing What Matters (DWM) for Jobs and the Economy framework supports the efforts of California's community colleges (CCs) to help students prepare for the creative, entrepreneurial economy. One key way to do this is through engaging with the Maker Movement by helping CCs establish makerspaces to provide users with important skill sets that compliment their education by incorporating new knowledge, technologies and tools into academic and career and technical education curriculums.

To inform these efforts, the California Council on Science and Technology (CCST), was contracted by the CCCCO to develop this report to provide background, considerations, and recommendations for establishing a network of community college-linked makerspaces. In addition to a background literature review, CCST has conducted a series of surveys and interviews with people engaged in a variety of makerspaces (see Acknowledgements). This "playbook" chapter describes important, common threads to consider when setting up makerspaces linked to the CCs, and provides recommendations based on them. Given the variation in makerspace models, there is no one-size-fits-all plan. Certain factors will need to be determined by each CC in order to fit individual and regional needs, with no one recommendation fitting all colleges (e.g. on-campus or off-campus location?). However, this document provides a strong framework to build on as the CCCCO DWM helps CCs expand and coordinate their engagement in Making.

Broadly, we recommend that the CCCCO consider supporting the formation of a network of ten or more makerspaces across the state. The makerspaces would be closely linked to community colleges, located either on or near campus, and offer low-cost access to community college students. The makerspaces should consider bringing in representatives of off-campus groups and act as a link between the college and the regional economy. A key way for CCCCO to support the formation of this network is by issuing a Request For Applications (RFA) for CCs to establish a new makerspace, expand the facilities or activities at an existing one, or serve as the state leader of the CC-makerspace network to maintain communication within, and offer key support to, the network.

Key Network Characteristics

To help guide the development of a CC-linked makerspace network by applicants and the CCCCO, we have compiled a list of key characteristics to consider:

- At least ten makerspaces associated with community colleges statewide.
- One lead institution to maintain regular communication, support the network with centralized resources, and identify opportunities to pool resources, as through sharing training materials and functioning as a hub for the collection of metrics data.
- Geographically dispersed across the economic regions identified by CCCCO DWM.
- Shared evaluation component that studies educational and workforce outcomes of the makerspaces.
- Makerspaces position community colleges as stakeholders in the regional economy via partnerships with businesses, government, community-based organizations, and foundations.
- Offer linkages to jobs and work-based learning opportunities, including at least 100 internships at each campus, for makerspace users.
- Makerspaces need strong support from CTE and STEM/STEAM faculty and administration to succeed; foster interaction and partnership between a diverse range of STEM/STEAM and CTE faculty on campuses, and ideally, have at least one full-time, dedicated staff person to run each campus space.
- Work with the local Academic Senate and college administration to create strong, mutually beneficial interactions between traditional course offerings and the makerspace.
- Integrate with traditional instruction framework by offering faculty opportunities to use the space for their classes, to conduct business and industry advisory meetings, and to receive training in new skills.
- Complement existing for-credit classes by offering badges, certificates, or for-credit courses in topics that are not offered at the college. Position the makerspace as a vital campus resource, similar to a library or computer center.

Network Purpose

Makerspaces offer opportunities for interdisciplinary, project-based learning opportunities for makers. The core goal of a makerspace is to provide a playground for invention, counting on the users' natural curiosity and drive to inspire the work. As such they are inherently different from most traditional classroom activities. However, educational institutions can and do use the resources of makerspaces for a host of activities. These can be fairly unstructured, such as giving students free time to be creative using tools that demonstrate a principle being explored in class. Or they can be fairly structured, such as asking students to use the makerspace and its equipment to create a project that will be graded in a traditional fashion, thereby essentially using the makerspace as a laboratory. Ultimately, what makes makerspaces distinct and exciting is that they are free-form and rely on the maker's intrinsic inquisitiveness and motivation to drive productivity. They are also incubators for innovation and can become a nexus through which the community college becomes a key player in the regional innovation economy.

Key Goals of the Makerspace Network

Though individual makerspaces will vary based on local needs, there are some key overarching goals to consider for the statewide network. Broadly, the network should:

- Give makers from the community college and beyond a space to use cutting-edge technology to collaborate, innovate, and become entrepreneurs.
- Offer opportunities to earn badges, certificates and credentials that are recognized and valued in the innovation economy.
- Build users' 21st century and soft skills that are vital for success in the workforce.
- Give community colleges a nexus by which they can position themselves as a key stakeholder in the entrepreneurial ecosystem.

Network Structure

A CC Maker Network would offer opportunities to share expertise, pool resources and offer support to its members. It could also help members connect to additional Maker networks outside of the CC system. Important features to consider incorporating into the network structure include:

- Leadership positions: a lead institution and appointed leaders closely affiliated with community college makerspaces with responsibility for growing the network and ensuring its success.
- A steering committee that can draw more broadly from stakeholders outside of the community college network, e.g.
    - CEOs from makerspaces outside the network
    - Executives from supportive businesses and foundations
    - Representatives of key Maker organizations such as Maker Media and FabLab
- Regular opportunities to meet and share knowledge, both virtually and in person, e.g.
    - Webinar meetings every other month on rotating topics
    - An annual in-person meeting covering a number of topics and bringing in outside experts; this could be held in conjunction with the Maker Faire, at which the CC-MS network might want to set up a networking booth.
- Sharing of staff resources for seeking financial sustainability, e.g.
    - Pool buying power for equipment/software
    - Pool staff time for grant applications and requests for donations of equipment and software
- While each makerspace should be unique given the needs of its campus and regional economy, the network can share a methodology for identifying how each makerspace will meet the overall network goals.

Varying Models can be Represented in the Network

Makerspaces are inherently grassroots organizations meant to serve their users. Successful makerspaces such as the Sierra College Hacker Lab emphasize developing their goals and structure based on early and regular input from stakeholders through formal channels (such as meetings with the campus Academic Senate) and informal channels (by hosting meetups with the local Maker community via meetup.com).

Activities at each makerspace should be customized to job opportunities available in the regional economy, as well as the interests and goals of students and other community members. For example, the choice of location on- or off-campus will depend on circumstances specific to each campus. By having a network of spaces, CCs can help one another figure out the details of which model characteristics best suit their needs. Similarly, while the development of the WBL/internship program at each makerspace will likely initially build off of existing internship program structures, the network of spaces can help advise one another on best practices for developing opportunities that fit with the local and regional businesses and industry.

Timeline

The following timeline is provided as a starting guide for a CCCCO grant program to establish a statewide makerspace network with key outcomes noted:

By December 31, 2016

- Request for Applications (RFA) issued.
- Network of 10+ makerspaces in California reviewed and funded.

By June 30, 2017

- New makerspace campuses: Assessments and community building efforts completed, campus workgroups organized and strategies in place. Makerspaces in process of being set up.
- Existing makerspace campuses: Strategy and business plan in place, community partners engaged, makerspace open and functioning, events and workshops delivered, students and faculty engaged.

By December 31, 2017

- All makerspaces funded through first RFA open and serving students, businesses and community members.
- Efforts to integrate and/or align makerspaces with academic programs and LaunchBoard Common Metrics underway.
- Sustainability plans developed and worked into the business plan.

By December 31, 2019

- Sustainability plans have been incorporated into operations.
- Network makerspaces are able to maintain operations through funding sources outside of the initial three-year RFA support.

Start Up Checklist – What do you need to consider when opening a makerspace?

Staff:

Typical staff roles may include:

- General manager – oversight, community relations
- Program manager – operations, technology, equipment, trainings
- Front desk/membership manager – manage membership, accessibility of space
- A few part-time staff members as needed – tend the space during open hours

Startup process plan:

A strategy to tap into the community of likely users and assess their needs and goals

- Meetups (http://www.meetup.com/) in conjunction with publicity through social media, email blasts to potential user groups, and traditional advertising are useful approaches.

Activities plan:

What activities will be hosted at the makerspace?

What badges, certificates, and/or for-credit courses?

- If for-credit courses are planned, the lengthy approval process should be started as soon as possible.

Space:

Based on CCST's background research, 4,000 square feet is often considered a minimum, while 6,000 – 10,000 square feet is preferred, though some spaces have started with less than 1,500 square feet; this will vary depending on the needs of the individual makerspace and the anticipated uses and student flow.

Various potential uses may need separate sub-spaces:

- Incubator offices for startups
- Co-working environment that could be repurposed for event space
- Private meeting rooms
- Separate rooms for equipment such as computers vs. equipment that generates dust and fumes
- Soundproof room for CNC machine

Also consider the infrastructure necessary for the equipment:

- High-speed internet
- Dedicated power lines to equipment with high electricity needs
- Electrical outlets, both 110 and 220 volt
- Dust control, exhaust, air circulation

Community and campus support:

Need support and close relationships with:

- Campus administration: at least one champion in the administration
- Faculty: at least one champion in the faculty
- Potential members, especially students
- Off campus community: local businesses and government leaders

Website and database:

Method for tracking members, hours, events and updating online calendar

Funding strategy:

Craft plan to reach self-sustainability after the initial three-year grant investment, as through one or more strategies:

- Membership fees
- CC-associated funds: District, campus, educational resource, course moneys
- Support, such as donations and grants, from outside groups: businesses, government, foundations

Learning Outcomes Achieved at Makerspaces

The educational goals achieved in a makerspace function on two levels: tangible skills, such as using a 3-D printer or CNC machine, and intangible skills, such as creativity and critical thinking.

Tangible skills

Can be measured with a system of badges, such as Mozilla Open Badges, which is an online badge system to verify skills, interests, and achievements through credible organizations (Mozilla, 2015). These skills could include abilities to use software and equipment that are employed in regional industries.

Intangible skills

Can be measured through human-scored metrics such as observations of behaviors or of products such as portfolios that demonstrate use of these skills (see Network Evaluation, below).

- 21st century learning and innovation skills (P21, 2015)
  - creative thinking
  - critical thinking
  - collaboration
  - communication
- Soft skills (Centers of Excellence for Labor Market Research, 2014)
  - critical thinking
  - problem solving
  - oral communication
  - written communication
  - teamwork/collaboration
  - leadership
  - creativity/innovation
  - self-direction
  - professionalism/work ethic

The specific learning objectives of each makerspace should align with the California Community College Career Technical Education LaunchBoard Common Metrics and to the needs of regional economy. Table A lists potential strategies for aligning the learning objectives of makerspaces with LaunchBoard Common Metrics Leading Indicators and Student Momentum Points, and ARCC 2.0 Scorecard metrics.

Network Evaluation

A key component of demonstrating success and improvement for the makerspace network is effective evaluation. However, evaluation of the goals of makerspaces will be challenging because it is complex to collect data demonstrating that makerspaces augment the 21st century skills, soft skills, and career readiness of makerspace users.

Here we propose two sets of metrics: one that is relatively straightforward to collect and focuses on easily quantifiable outcomes (questionnaire-style), and a second set that is based on monitoring how users spend their time at makerspaces (behavioral).

Many of the metrics below are likely collected as standard procedure by the community college. If the makerspace collects student identifiers of all community college students who use the space, it would be possible to compare metrics for students who use the makerspace versus those who do not. For example, are students who use the makerspace more likely to complete a certificate, associates degree, or transfer to a four-year college than students who do not? How do the GPAs and demographic profiles of students using the makerspace compare to the rest of the student body? After graduation, are students using the makerspace more likely to find a job in their major or have a higher starting salary in industry? Ultimately, collecting such statistics will be useful to demonstrate the types of students the makerspace serves, although the approach would be limited by being correlational.

In order to prove that the makerspace is causing any differences in student performance, one would have to randomly select students to be recruited for the makerspace and compare them to a similar group of students who do not use the makerspace. Organizing such a rigorous comparison is possible, though that would require a greater investment of staff time than simply looking at correlations.

Questionnaire-Style Metrics

CCs already collect a great deal of descriptive, qualitative, sustainability indicator, and work-based learning data, such as student degree completion, GPA, internship participation, etc. This information, along with additional quantifiable metrics, could potentially be collected for those enrolled community college students using the makerspace to assess outcomes of success and student trajectories. Some metrics could be available in the short-term, providing annual results, while others would need to be developed and added to existing information systems for long-term results, after 3-6+ years. Examples may include:

1. Number of measurable products completed, e.g. documented projects such as can be documented on instructables.com or as a maker portfolio.[1]
2. Workshops, badges, certificates, and/or for-credit courses completed (in a CTE pathway).
3. GPA (in a CTE pathway).
4. Percent completing a certificate program (in a CTE pathway).
5. Percent participating in a CTE pathway who transfer to a four-year institution.
6. Percent obtaining a job (in a CTE pathway).
7. Number of students successfully completing a 6-week internship (in a CTE pathway).

For all individual makerspace users:

1. Number of community college students, faculty, businesses and community members served.
2. Demographics of users.

For the makerspace as a member of the regional economy:

1. Is the makerspace receiving contributions (cash and in-kind) from local businesses and government?

[1] Maker portfolios are commonly used in the maker community to show an individual's work. Maker Ed is leading an effort to standardize the process in a way that incorporates best practices; see http://makered.org/opp/research-briefs/.

2. Has the makerspace established job opportunities or internships for users with local businesses?
3. Do regional employers recognize and value badges, certificates or credentials earned at the makerspace?

Behavioral Metrics

The goal of measuring behavioral metrics is to document how and when makerspace users are practicing soft skills and 21st century skills. These skills are demonstrated as behaviors that are recorded by a trained observer using a consistent rubric. The Exploratorium developed a Learning Dimensions Framework that they used to categorize activities demonstrated by people engaged in activities at their Tinkering Studio (Exploratorium, 2015a; Exploratorium, 2015b). Table B gives the Exploratorium's Dimensions of Learning in the first three columns. The third column, "Descriptor-Learner" is a list of behaviors demonstrated by makerspace users that indicate engagement in a learning process. Columns 4 and 5 list the soft skills and 21st century skills that correspond to each behavior. The Exploratorium also offers a training guide in how to use the Learning Dimensions Rubric and has posted their database and video clips to help demonstrate (Exploratorium, 2015a). The Learning Dimensions Framework offers one method by which the network could consistently document important skill sets in practice at the makerspaces.

Practical Considerations for Makerspaces

Location: On- or Off-Campus?

Locating the makerspace in the community can encourage broader involvement beyond the college network. An on-campus facility may be easier to integrate with the campus community. Other considerations include administrative requirements, cost, space availability, and whether there already is a public makerspace nearby. Community colleges located in high-rent areas may find the cost of renting off-campus commercial space cost-prohibitive.

Examples of On- and Off-Campus Makerspaces Linked to Community Colleges

On-campus makerspaces
Portland Community College Makerspace (Portland, Oregon)
Laney College FabLab (Oakland, California)

Off-campus makerspaces
Sierra College Hacker Lab (Rocklin, California)
i-Gate partnership with Las Positas College (Livermore, California)

Open Hours

Makerspaces thrive on being easily accessible and a hub for community activity. Maximizing open hours when staff are on-site and offering keycard access to members during unstaffed times help build a thriving community of users at the makerspace. Based on a survey of three successful makerspaces, we found that the fewest open hours was at Portland Community

College Makerspace in Portland, Oregon, which was open 34 hours a week, and only while staff was present. At the other end of the spectrum was Sierra College Hacker Lab in Rocklin, California, which is staffed 45 hours a week, but is accessible to members 24/7. The Case Western Reserve University Makerspace in Cleveland, Ohio is open 63 hours a week, excluding breaks and holidays, and is accessible only while staff is present.

Infrastructure, Equipment and Software

There are a number of important considerations in setting up the physical space, equipment and software in a makerspace. The appropriate space and equipment should be selected after soliciting input from stakeholders on target activities at the makerspace. Appendix C lists a number of considerations and resources to consult on outfitting a makerspace.

Funding and Sustainability

Makerspaces need to consider a number of sources of revenue for long-term sustainability. Sources to consider include:

- Membership dues
    - Some makerspaces charge students from the host campus, albeit typically at a reduced rate relative to other members; others do not.
- School district funds
- Foundations
    - Most large corporations have a foundation or charitable contributions division which can be contacted for potential support.
- Federal agencies (e.g., National Science Foundation, National Institute of Standards and Technology [NIST], Defense Advanced Research Projects Agency [DARPA], U.S. Department of Commerce)
- Local government (e.g., city and county grants)
- Business sponsors
    - Businesses sponsor an event that publicizes their company, donating money for the event and general operating costs.
    - Local businesses are often more willing to give non-monetary support by volunteering time (e.g. to an advisory board or as teachers), or in-kind donations of equipment and software.
- For-credit classes bring money from the General Fund
    - Teaching Assistant (TA) funds can provide non-instructor support staff during for-credit classes.
    - To offer for-credit classes through the makerspace, there are a number of considerations: the makerspace needs to work closely with faculty wishing to run classes; the space must be state-architect approved; and classes need to be approved through the certification process.
- Funding models similar to existing campus resources such as libraries and computer labs
    - To accomplish this, makerspaces would need to be classified by the CC system statewide as a campus resource.

In Table C we provide estimated baseline costs for the three-year setup and operation of a California Community College Makerspace Network, with ten makerspaces, internship/WBL programs, and central network leadership staff. While the authors take responsibility for the end result, the budget was compiled with helpful input from Gina Lujan and Eric Ullrich of Hacker Lab, and Danny Beesley, Owner, Idea Builder Labs, and Consultant for Laney College, Castlemont, McClymonds, and Fremont High School FabLabs. We estimated the cost of starting up and running a reasonably well-equipped makerspace over the initial three-year period at approximately $905,000. However, with modest expenses, including such things as the use of campus facilities, thereby eliminating rental space costs, and drawing from faculty for training instead of an outside consultant, costs could be reduced to approximately $610,000 for an individual makerspace over three years.

To fund the network leadership, we very roughly estimated enough funding for a couple of options. First, for staff at a lead college supporting the network, we estimated three staff people at 10 hours a week for three years at $50 an hour, plus or minus 10%. As an alternative, a technical assistance provider (TAP), based at the CCCCO could support the network, at an estimated cost of $240,000 per year for 3 years, including travel to the campuses. We also allocated funds for an annual conference and miscellaneous operating expenses such as teleconferences. As well, estimates are included for CCST to provide continued support and evaluation for the project, grant development, and information dissemination over three years. This yielded a total cost of network leadership for three years of approximately $931,000. Adding the cost of network leadership to the cost of opening and operating ten makerspaces yields a total midpoint grant budget of $9.98 million.

Makerspaces in Relation to Traditional Course Offerings

Makerspaces need strong support from faculty and administration to succeed. Makerspace leaders will need to work with the Academic Senate to create strong, mutually beneficial interactions between faculty and the makerspace. It is important that the makerspace be perceived as a complement to, rather than in competition with, traditional classroom offerings.

Makerspaces can integrate with a community college's traditional instructional framework by offering faculty opportunities to use the space to hold classes (either for every meeting or for occasional laboratory sessions), hold business and industry advisory meetings, and for faculty to receive training in new skills.

Makerspaces can complement existing for-credit classes by offering badges, certificates, or for-credit courses in topics that are not offered at the college. Ideally the makerspace becomes one of an array of campus educational resources, along with the library and computer center. For makerspaces to align with LaunchBoard's Common Metrics (Leading Indicators and Student Momentum Points), and SSTF Student Success Scorecard metrics, they will need to develop badges, certificates, or course offerings within a CTE pathway.

An additional consideration when setting up a network of makerspaces at the CCs is the possibility of linking to four-year and doctoral degree granting institutions and federally funded laboratories to develop mechanisms for the network to have access to specialized high-tech facilities and tools. These might include nanotechnology, advanced materials, photonics, micro-machining, etc. The network of CCs with makerspaces should investigate possible collaborations with such resource-sharing programs in California to further expand the opportunities available to faculty, students, and other users. Examples of such programs include the Information Sciences Institute through the University of Southern California's Viterbi School of Engineering, the San Diego Supercomputer Center through UC San Diego, and Cyclotron Road, which is a public-private partnership founded by Lawrence Berkeley National Laboratory to support critical technology development.

Makerspaces as a Link Between Community Colleges and their Regional Economies

Makerspaces are not simply a new and different way to train community college students for the workforce. They can also serve as key participants in a region's economy. As such they can strengthen the connection between community colleges and other members of the entrepreneurial ecosystem including businesses, local government, community-based organizations, other makerspaces and incubator spaces, workforce investment boards, foundations, and other institutions of higher education. Makerspaces can be a vital bridge for their student body to come in contact with businesses, understand how they function, and find training and job opportunities. Forming partnerships with other members of the entrepreneurial ecosystem is essential not just to bring financial resources to the makerspace but is fundamental to its mission of integrating community college students, particularly those across CTE pathways and STEM/STEAM curricula, into the broader community.

Key strategies for building partnerships include:

- Bringing in entrepreneurs and supporting businesses (e.g. legal, banks, marketing) to do trainings and mentor students.
- Asking partnering organizations to sponsor events (such as hackathons) and make donations.
- Providing clear linkages from makerspace to internships and job opportunities.
- Establishing credibility of MSS micro-credentials in the local business community.

One example of a broad partnership initiative from the CC's Doing What Matters framework is the Centers for Applied Competitive Technologies (CACT). The CACT is a founding member of the California Network for Manufacturing Innovation (CNMI), a non-profit corporation that promotes manufacturing competitiveness through the collaboration of industry, national laboratories, academia, and workforce and economic development organizations. The CNMI has held joint symposia to education and share new methods and technologies.

Key Findings and Conclusions

Makerspaces are an important tool for growing a strong workforce. In addition to knowledge gained in traditional teacher-led classrooms, makerspaces help users develop complementary skills sets. The best teachers and students have always brought the values of the Maker Movement into the classroom, but having a designated makerspace is an opportunity to focus on the experience free from classroom constraints.

To ensure successful integration of makerspaces, California Community Colleges need to establish means of measuring outcomes that do not rely on standardized testing or a focus on a target product. There is a range of metrics that can be used, including human-scored rubrics focusing on process not product, documentation and communication to peers of projects outcomes rather than grades, as well as certificates, badges and workshops to complement transcript-credit courses. The makerspaces should work to provide an interdisciplinary setting, bringing together students from across CTE pathways and STEM/STEAM courses, to provide a rich, collaborative environment.

In order to set up a network of 10 makerspaces among CCs and support them for three years, grant budget estimates average approximately $10 million. These overall costs will depend on how each makerspace is set up in order to best address local and regional needs. The network will be key to comprehensively building and supporting a CC-linked system of makerspaces for the benefit of not only students and faculty, but also governments, businesses, and local communities.

Acknowledgments

Special thanks to Carol Pepper-Kittredge of Sierra College, Gina Lujan of Hacker Lab, Danny Beesley of Idea Builder Labs and Consultant for Laney College Fab Lab, Trey Lathe of MakerEd, Frank Paton of the Paton Group, Monika Mayer of Lawrence Hall of Science, Eric Ullrich of Hacker Lab, Mike Petrich of the Exploratorium in San Francisco, Brandon Cardwell of i-GATE, Zachary Dowell of Folsom Lake College, Joe Klocko of the College of the Canyons, Amy Schulz of the National Association for Community College Entrepreneurship, Jessica Parker of Sonoma State University, Sue Weber of the Indian Valley Academy, and Dale Dougherty of the Maker Education Initiative and Maker Media for making time to speak to the authors and provide invaluable insight.

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Table A. Potential strategies for aligning Makerspaces with LaunchBoard Common Metrics Leading Indicators and Student Momentum Points, and ARCC 2.0 Scorecard metrics. Accountability and measurement of grant activities administered through CCCCO's Workforce and Economic Development Division is based on the Accountability Reporting for the Community Colleges (ARCC) 2.0 framework, with three categories of measurements. Makerspaces have potential to satisfy common metrics in two measurement categories: leading indicators of curriculum alignment to labor market needs and student momentum points, as described below. Line numbers correspond to the numbering in (California Community Colleges Chancellor's Office, n.d.).

Common Metrics Applicable to Requests for Applications of the Division of Workforce and Economic Development

	Leading Indicators of Curriculum Alignment to Labor Market Needs	**Potential Strategies to Align Makerspace to Common Metric**
1	Alignment of skillsets within a program (or set of courses) to a particular occupation and the needs of the labor market	Evaluate behavior in makerspace for demonstration of soft skills and 21st century skills, as well as technical skill sets required in regional economy (e.g. computer literacy, 3-D printing, etc.)
3	Alignment of a certificate with state-, industry-, nationally-, and/or employer-recognized certification	Align badges and/or certificates awarded in makerspace with state-, industry-, nationally, and/or employer-recognized certification
6	Updating the skills of faculty, teachers, counselors, and/or 'supporting staff to student' to reflect labor market needs	Provide training opportunities in labor-market needs for community college faculty, teachers and counselors in makerspace
7	Integration of small business creation and/or exporting modules into for-credit curriculum in other disciplines	Support activities leading to small business creation in makerspaces, e.g. by offering a collaboration space for startups and with instruction modules on small-business creation

	Student Momentum Points	
	Community College Cluster	
15	Completed two courses in the same CTE Pathway	Offer for-credit courses and/or certificates within CTE pathways at the makerspace
17	Completed a non-CCCCO-approved certificate within a CTE pathway	
18	Completed a CCCCO-approved certificate within a CTE pathway	
19	Completed a work readiness soft skills training program (either stand-alone or embedded) within a CTE pathway	Offer work readiness soft skills program within a CTE pathway at makerspace

	Community College Transition to Workforce Cluster	
27	Participated in a college internship or workplace learning program within a CTE pathway	Establish opportunities for internships with makerspace staff, workplace learning programs with startups and small businesses within a CTE pathway associated with the makerspace
28	Attained a job placement in the same or similar field of study as CTE pathway	Track job placements for students who participate in makerspace activities
29	Acquired an industry-recognized, third-party credential	Offer opportunities to earn industry-recognized, third-party badges or credentials at the makerspace
33	Participated in incumbent worker training or contract education in a CTE pathway	Offer opportunities for incumbent worker training or contract education in a CTE pathway
34	Exception: for grants providing direct services to an employer, a group of employers, or an industry sector or industry cluster (including small business and global trade), if there is not alignment within any of the Student Momentum Points and/or Learning Indicators listed above, perform an assessment of the purported 'beneficial impact' of the grant on the relevant businesses, which may include a review of the grant's purported impacts on any of the following: increased profitability, increased labor productivity, reductions in worker injuries, employer cost savings resulting from improved business processes, improved customer satisfaction, increased employee retention, increased number of employees, increased revenue projections, increased sales, penetrated new markets, as well as information on new products or services developed	Evaluate potential of grant to improve makerspace performance in any of the listed beneficial impacts.

ARCC 2.0 Scorecard

CAREER TECHNICAL EDUCATION (CTE) RATE Definition: For three cohort years, the percentage of students who completed a CTE course for the first-time and completed more than eight units in the subsequent three years in a single discipline (2-digit vocational TOP code where at least one of the courses is occupational SAM B or C) and who achieved any of the following outcomes within six years of entry:	
Earned any Associate in Arts/Associate in Science or credit Certificate (Chancellor's Office approved)	Support for-credit courses as laboratory space or offer for-credit courses in makerspace in a CTE pathway
Transfer to four-year institution (students shown to have enrolled at any four-year institution of higher education after enrolling at a California Community College)	
Achieved "Transfer Prepared" (student successfully completed 60 University of California or California State University transferable units with a GPA >= 2.0)	

Table B. Behaviors in a makerspace as they relate to Soft Skills and 21st Century Skills necessary for workforce success.

Dimensions of Learning[1] in a Makerspace

Dimensions of Learning	**Indicators**	**Descriptors - Learners:**	**Soft Skill[2]**	**21st Century Learning/Life Skill[3]**
Engagement	Displaying motivation or investment through affect or behavior	play, envision, make, explore materials, try something over and over, etc.	problem solving	Creative Thinking
		show emotions such as joy, pride, disappointment, frustration	communication	Communicating
		remain after they appear "finished," and start something new	self-direction	Initiative
Initiative and Intentionality	Setting one's own goals	set goals / pose problems	creativity/innovation	Creative Thinking
		plan steps for future action	creativity/innovation	Creative Thinking
		develop unique strategies, tools, objects or outcomes	problem solving, creativity/innovation	Creative Thinking
		state intention to continue working outside Studio	self-direction	Initiative
	Seeking and responding to feedback	actively seek out feedback or inspiration from materials/environment	problem solving, creativity/innovation	Creative Thinking
		anticipate further outcomes	self-direction, problem-solving	Critical Thinking
		innovate approaches in response to feedback	problem solving, creativity/innovation	Creative Thinking
	Persisting to achieve goals in the problem space[4]	persist toward their goal in the face of setbacks or frustration within the problem space	self-direction, problem-solving	Critical Thinking, Initiative, Flexibility

		persist to optimize strategies or solutions	problem solving, professionalism/work ethic	Critical Thinking, Initiative
	Taking intellectual risks or showing intellectual courage	disagree with each other's strategies, solutions, or rationales	leadership	Creative Thinking, Critical Thinking
		try something while indicating lack of confidence in outcome	self-direction	Flexibility, Initiative
Social Scaffolding	Requesting or offering help in solving problems	in the role of novices or experts, request or offer ideas and approaches	teamwork/collaboration, oral/written communication	Collaborating, Communicating, Social Skills
		in the role of novices or experts, offer tool(s) or materials in service of an idea	teamwork/collaboration, oral/written communication	Collaborating, Communicating, Social Skills
	Inspiring new ideas or approaches	notice, point out, or talk about others' work	teamwork/collaboration, oral/written communication	Communicating, Social Skills
		innovate and remix by using or modifying others' ideas or strategies	creativity/innovation, teamwork/collaboration	Collaborating, Creative Thinking
		leave something of their work behind to share with others	teamwork/collaboration	Collaborating, Communicating
	Physically connecting to others' works	produce work that physically interacts with other learners' work	teamwork/collaboration	Collaborating
Development of Understanding	Expressing a realization through affect or utterances	show excitement when expressing a realization	enthusiasm, communication	Critical Thinking
		claim to realize or newly make sense of something	enthusiasm, communication	Communicating, Critical Thinking

Offering explanation(s) for a strategy, tool or outcome	Learners offer or refine explanation(s) for a strategy, tool or outcome, possibly by testing and retesting	critical thinking	Communicating, Critical Thinking
Applying knowledge	connect to prior knowledge, including STEM concepts	critical thinking	Critical Thinking
	employ what they have learned during their explorations	critical thinking	Critical Thinking
	complexify by engaging in increasingly complicated and sophisticated work	creativity/innovation	Creative Thinking, Initiative
Striving to understand	Learners indicate not knowing (e.g., through surprise, bewilderment, confusion) and remain in the problem space to explore their confusion and build an understanding	critical thinking, self-direction, professionalism/work ethic	Initiative

[1]The Dimensions of Learning framework was developed by the Tinkering Lab at the Exploratorium to "describe four categories of learning that we value in Tinkering activities" (Exploratorium 2015).
[2]Soft skills identified in "Small Business Survey in the Inland Empire and Low and High Desert Regions" http://www.coeccc.net/documents/Small%20Business%20Survey%20report.pdf#search
[3]21st century skills identified by Partnership for 21st Century Learning, http://www.p21.org/storage/documents/P21_framework_0515.pdf
[4]A problem space is a collection of questions, problems, materials, and solutions associated with trying to make something happen within the framework of the activity. For example, trying to keep a marble from falling off a track would be working within a problem space in Marble Machines. Distinguish between PS and just being in the TS.

Table C. Estimated Three-Year Costs for Community College Makerspace Network.

	Low end	High end	Midpoint
I. Makerspace Three-Year Budget			
First year costs			
Startup equipment and furniture costs	100,000	300,000	200,000
Facility buildout, e.g. electrical wiring, air circulation	10,000	50,000	30,000
Outside consultant for training as needed, coordinated by network leadership	10,000	30,000	15,000
Annual costs			
Staffing ($90,000-100,000/year x 3 years)	210,000	330,000	255,000
Rent (4,000–10,000 sq ft space); will vary widely if on or off campus, local rates	0	180,000	90,000
Marketing and web site	10,000	30,000	15,000
Internship/work-based learning program and support (~$100,000/yr x 3 years for 100 internships paid @ $10/hr for 6-week internships with program staff support)	270,000	330,000	300,000
Three-year budget for a makerspace	**610,000**	**1,250,000**	**905,000**
II. Network Leadership Budget			
Staff ($70,000-90,000/year x 3 years)	300,000	720,000	600,000
Annual conference ($10,000-20,000/year x 3 years)	30,000	60,000	45,000
Miscellaneous - office expenses, teleconferences, travel (~$8,000-$10,000 x 3 years)	24,000	30,000	27,000
CCST program development and support for 3 years	236,082	309,090	259,444
Three-year budget for network leadership	**590,082**	**1,119,090**	**931,444**
III. Grant Competition Budget (I + II)			
Fund startup and three years of operation for 10 makerspaces	6,100,000	12,500,000	9,050,000
Fund three years of operation of network leadership	590,082	1,119,090	931,444
Total grant competition budget	**6,690,082**	**13,619,090**	**9,981,444**

Appendix A. Definitions

a. **Fab Labs**: Often thought of as a type of makerspace, these are spaces that commonly share a core set of digital fabrication and prototyping tools, for example, laser cutters, vinyl cutters, cNc routers, and 3D printers, and that emphasize making using digital technology.
b. **Hackerspace**: Also thought of as a more specialized type of makerspace, these are spaces largely associated with adult, computationally focused making that emphasize forms of making utilizing digital technologies, similar to fab labs.
c. **Makerspace**: Broadly, makerspaces are places where people can design and invent among a community of other makers and that emphasize 21st century skills, including creative thinking, critical thinking, collaboration, and communication; these spaces offer interdisciplinary, participatory, and peer-supported learning environments.

Appendix B. Outfitting a Makerspace

1. Most Common Costs:
   a. Equipment
   b. Software
   c. Staff
   d. IT Support
   e. Faculty
   f. Administration
   g. Overhead
   h. Infrastructure
   i. Utilities
2. Physical Infrastructure Considerations:
   a. Size
   b. Safety, e.g. determine if OSHA approval needed
   c. Soundproofing for loud equipment
   d. Wiring: Electricity (110 and 220 volts), internet
   e. Power, e.g. may need dedicated power lines for equipment with high power needs such as 3D printer and laser cutter
   f. Dust control, exhaust, air circulation
      i. Need exhaust hoods and filters for some types of equipment, e.g. laser cutters need exhaust because cutting acrylic is toxic
      ii. Useful to have a separate dirt room and clean room
3. Resources on Outfitting a Makerspace

   Fab Foundation, Setting Up a Fab Lab web page:
   http://www.fabfoundation.org/fab-labs/setting-up-a-fab-lab/

   Inventory of hardware and materials in a full Fab Lab:
   http://fab.cba.mit.edu/about/fab/inv.html

Appendix C. Makerspace Budget Example

Danny Beesley (Owner, Idea Builder Labs, and Consultant for Laney College, Castlemont, McClymonds, and Fremont High School FabLabs) generously shared his planning list and budget for materials and equipment for the first year of the Laney College FabLab. He notes that this document was not intended to be prescriptive but simply should be regarded as an example. The prices listed were current in 2015.

This document is available for download as a separate Excel spreadsheet, called "Appendix C_Beesley_fablab_basic budget_and_equipment.xlsx."