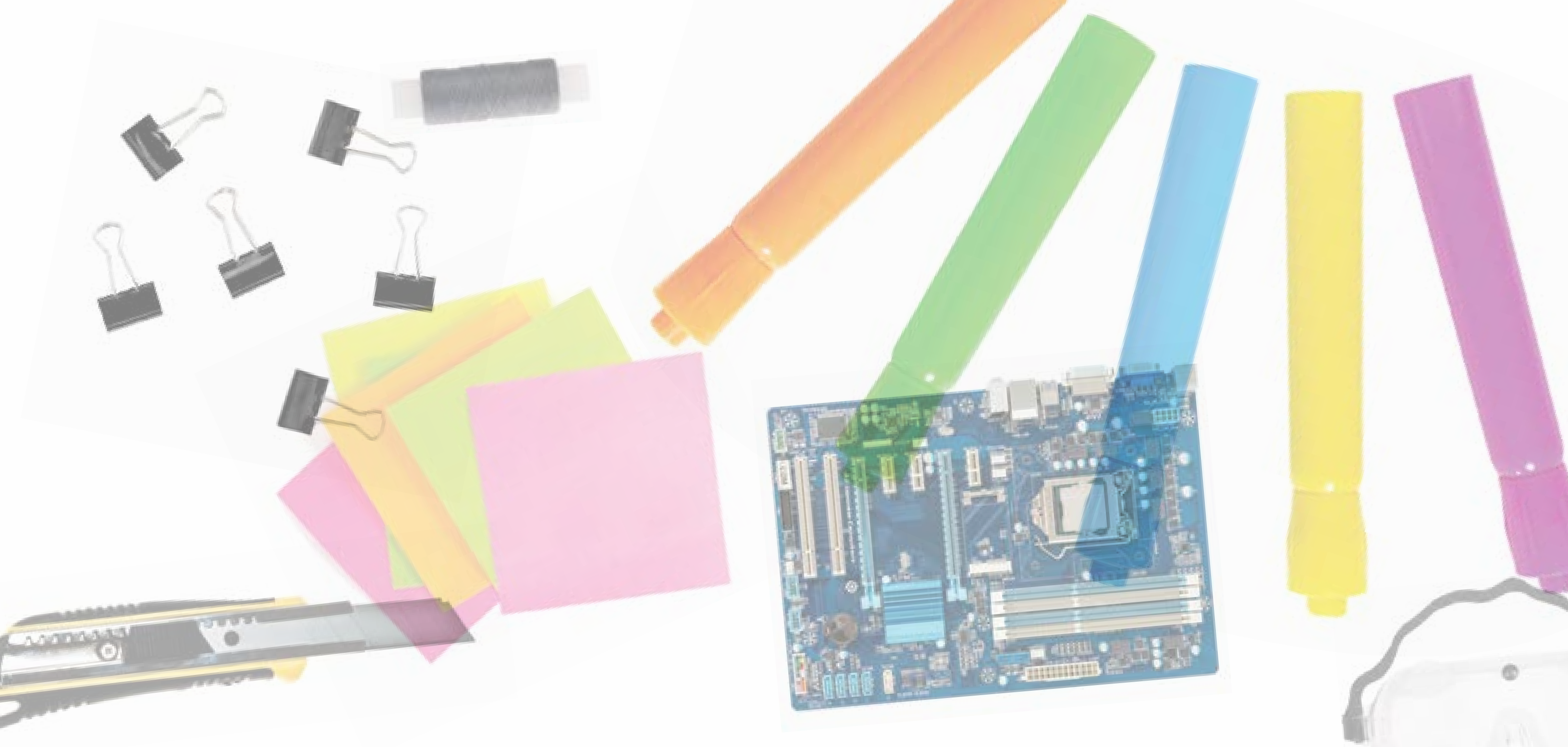
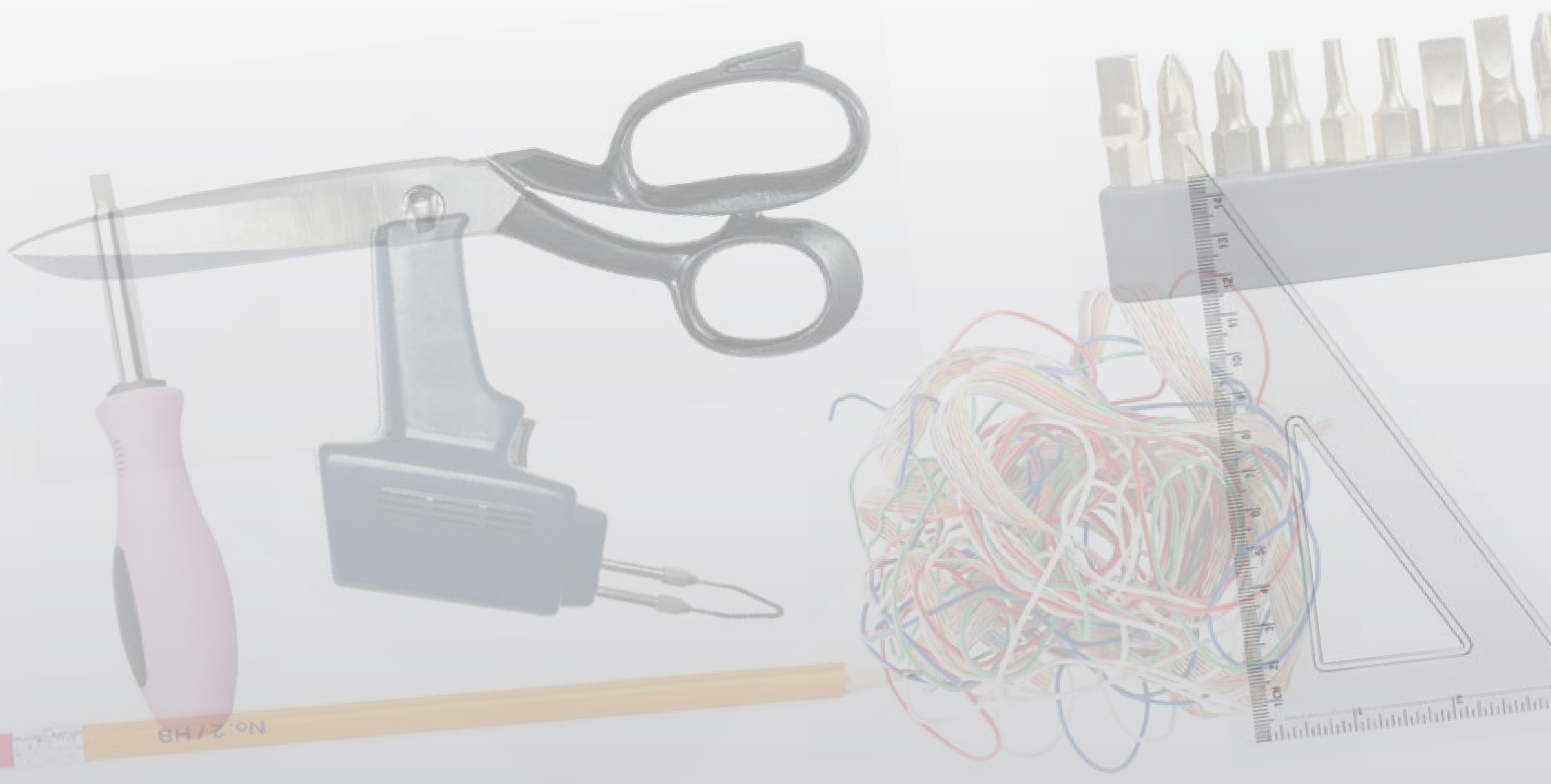


Advancing the Maker Movement:

Making and Makerspaces at Engineering and Engineering Technology Schools and Departments and Outside the Engineering Academic Maker Community



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Advancing the Maker Movement: Making and Makerspaces at Engineering and Engineering Technology Schools and Departments and the Non-Engineering Academic Maker Community

American Society for Engineering Education
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Washington, DC 20036

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Advancing the Maker Movement:

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September 2017

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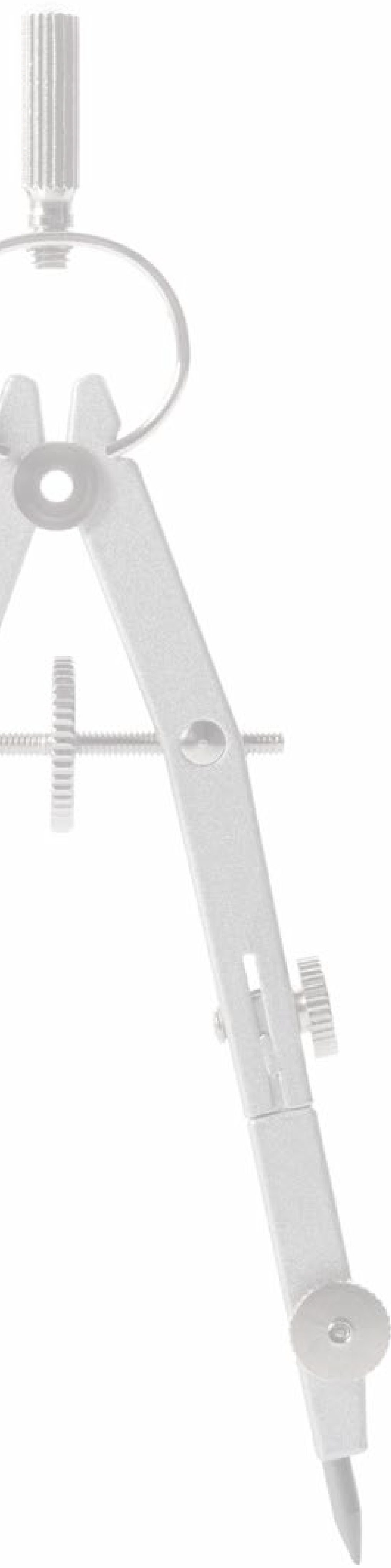

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In the ASEE's Art Department, Francis Igot provided the layout and design and Michelle Bersabal oversaw the production process.

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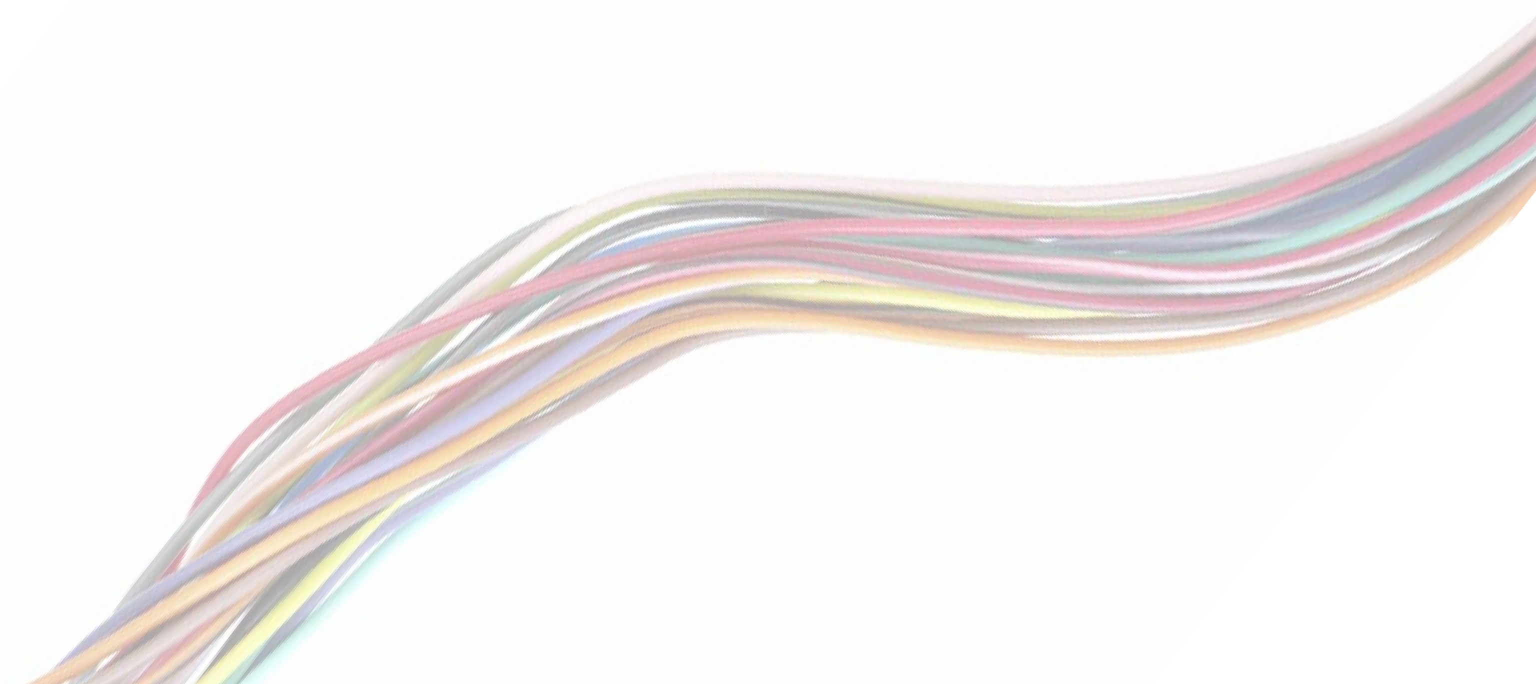


Executive Summary

The use of Making and Makerspaces in engineering and engineering technology departments and programs has proliferated over the past decade. While research has documented Makerspaces and Making activities at universities (for example, the MakeSchools initiative, managed at Carnegie Mellon University, documents Making at different universities), little research has gone into understanding how engineering deans and engineering technology deans and department chairs view Making. In particular, little is known about how making is incorporated into their departments and programs; what engineering deans and engineering technology deans and department chairs view as the value of Making for engineering and engineering technology; and how making is supported at their universities. Also, little research has explicitly looked at what engineering deans and engineering technology deans and department chairs can learn from a non-Engineering academic Maker community that extends beyond engineering and engineering technology, and how Making can help attract diverse groups to engineering and engineering technology.

To fill this gap of knowledge, we sent out surveys to engineering deans and engineering technology deans and department chairs, and a separate survey to the non-Engineering Maker community. Most of the responses that we received from the survey sent to the non-Engineering Maker community could be characterized as coming from the non-Engineering academic Maker community, a subset of the Maker community. Our main findings include:

- Engineering deans and engineering technology deans and department chairs and the non-Engineering academic Maker community all define Making as taking an idea or concept and creating it in material form. But, engineering deans and engineering technology deans and department chairs also defined Making as engaging students in hands-on engineering activities while the non-Engineering academic Maker community defined Making as a community oriented activity that is hobby-focused and brings personal satisfaction.

- Most engineering deans and engineering technology deans and department chairs reported having a Makerspace or multiple Makerspaces on campus. Those who reported multiple Makerspaces more frequently reported integrating Making into their curriculum and programs and more frequently reported positive student outcomes attributed to Making than respondents who reported one or no Makerspace on campus.

- Not all engineering deans and engineering technology deans and department chairs have the same view of what constitutes a Makerspace. While all respondents viewed designated spaces that housed 3D printers and scanners, laser cutters, or automatic and robotic systems as Makerspaces; some respondents did not view spaces that housed carpentry tools, machine shops, and fabrication labs as Makerspaces.

- One suggestion from the non-Engineering academic Maker community on how to use Making to attract diverse students to engineering is to provide Making opportunities for K-12 students so they learn design and engineering processes like prototyping and testing, and to use Making as an opportunity to raise awareness among K-12 students of engineering as a profession and a field of study.

Introduction

Although the term "Making" is credited to the 2005 founding of *Make:* magazine by Maker Media, a formal definition has yet to be established. Instead of defining the concept in set terms, recent sources have characterized it by the many activities that emphasize its creative and experiential aspects, often in the form of action verbs. In a 2014 interview with Phil Larson of the White House Office of Science and Technology Policy, Maker Media CEO Dale Dougherty loos ely defined Making as "creating, producing, crafting, shaping, tinkering, composing, and building" (Larson, 2014; ASEE, 2016). In a survey of Makers at the 2012 World Maker Faire in New York City, Lande, Jordan, and Nelson noted the most frequent verbs used to define Making were "making," "doing," and "creating" (2013). Anderson (2012) asserted that *everyone* is a Maker, including practitioners of gardening, cooking, and scrapbooking. Through a thorough review of recent literature, Martin created a working definition of "Making," as a "class of activities focused on designing, building, modifying, and/or repurposing material objects, for playful or useful ends, oriented towards making a 'product' of some sort that can be used, interacted with, or demonstrated" (2015, p. 31). Those who partake in the act of Making are known as "Makers." As a group, Makers are a growing community of creative individuals who engage in Making activities, representing a wide variety of backgrounds, interests, and levels of expertise. Lande, Jordan, and Nelson noted that Makers are "thought leader[s]" and are often defined and identified in the context of the larger Maker Movement (2013, p. 1).

The birth of the modern Maker Movement can be attributed largely to the recent growth and prevalence of digital culture, along with increased accessibility of electronics, software, hardware, and tools. As noted by Voigt et al. (2016), Bajarin (2014), Evgeny (2014), Martin (2015), and Anderson (2012), these factors transformed consumers into creators. Sources have also acknowledged the catalytic and supportive role that *Make:* magazine and Maker Media have played in the development and growth of the movement. Both Dougherty (2014) and Martin (2015) recognized *Make:* as a movement catalyst. A 2011 *Economist* article noted *Make:* magazine's influence as a "central organ of the movement" (p. 3) and Morozov (2014) described it as a cheerleader for Makers, acknowledging that the "intellectual infrastructure" provided by Maker Media allowed Makers to develop and share their skills and creations (para. 14). One of the main places where Makers can collaborate and share processes and products is a Makerspace. Makerspaces can be located in a wide variety of places, including libraries, art galleries, museums, laboratories, and workshops. Although Makerspaces can vary greatly, Davee et.al. defined them "fundamentally [as] places to design, explore, and create" (2015, p. 3). Recent "SHOP Act" legislation provides an operational definition of Makerspace as "a community space that provides access to tools, technology and knowledge for learners and entrepreneurs, which result in the prototyping or creation of physical goods, and which supports the development of educational opportunities for personal growth, workforce training, and early stage business ventures" (H.R. 2308, 2017).

Making gained significant visibility due to President Obama's support for the Maker Movement, culminating in the 2014 White House Maker Faire, a newly established National Week of Making, and the Nation of Makers Initiative. The latter was a call to federal agencies, companies, organizations, and schools to increase Making opportunities and technologies for students, entrepreneurs, and the general public. Commitments resulting from this initiative showed that Making could make a promising contribution to STEM learning. For instance, the National Science Foundation pledged to invite early concept proposals on STEM-related Making projects. A group of more than 150 academic institutions dedicated to supporting Making on their campuses formed the MakeSchools Higher Education Alliance (The

White House, 2014). The Alliance's 2015 report on the state of Making listed the three most important factors for creating a Maker culture on campus: 1) resources and environment (e.g. an established Makerspace and a collaborative atmosphere); 2) education and training for both students and faculty; and 3) opportunities for students to showcase their work (p. 13). In academic settings, Making and Makerspaces often embrace the principles of experiential learning.

University Makerspaces

In academic engineering and engineering technology settings, Making offers many parallels to experiential education, most notably a shared emphasis on both hands-on learning and self-directed, iterative learning experiences. Experiential education recognizes risk-taking and experimentation beneficial to learning, asserting that these features of the learning process further engage the learner and allow them to better construct meaning from the experience, resulting in increased creative skills and real-world connections (Association for Experiential Education, 2016). Iterative learning experiences are becoming more common in engineering and engineering technology education, particularly with the spread of academic Makerspaces. Foster, et al. (2015) noted that design education and active pedagogies help advance engineering education, and Making experiences can increase both knowledge (conceptual, procedural, and analytical) and practical skills. Barret, et al. (2015) reiterated the importance of hands-on learning experiences in engineering education. They noted that physical modeling and prototyping in university Makerspaces help improve design quality and connect class lessons to real-world issues, and that consistent iteration helps both "mitigate design fixation" and "reinforce[s] . . . adaptive and creative thinking" (p. 2). University Makerspaces serve as a central location for students to practice knowledge learned in the classroom and hone their design skills.

The first university Makerspace was implemented in 2001 at the Massachusetts Institute of Technology (MIT). As of June 2015, there were 40 university Makerspaces among the *U.S. News and World Report's* 100 top-ranked undergraduate engineering programs for 2014 (Barrett, et al., 2015). Though university Makerspaces vary in size, location, staffing, and accessibility, there are several characteristics shared by all. Barrett, et al. (2015), Forest, et al. (2014), and Wilczynski (2015) all noted the sense of community embraced by university Makerspaces, as exhibited by an environment conducive to collaboration among students. Morosz, et al. (2015) posited that Making activities in university Makerspaces can improve retention and encouraging broader participation in engineering, noting that "there is a strong relationship between the amount of engineering experiences and engineering design self-efficacy," a quality that has been shown to increase retention among underserved groups (p. 3).

By now, a growing body of research describes university Makerspaces, their best practices, and the specific ways that they can benefit engineering education. The surveys conducted for this report sought to add further to the literature on how engineering deans and engineering technology deans and department chairs define Making; identify positive student outcomes engineering deans and engineering technology deans and department chairs attribute to Making; describe ways in which Making is integrated into engineering and engineering technology programs; describe how the non-Engineering academic Maker community defines making, how the non-Engineering academic Maker community engages others in Making, and how they fund and manage Makerspaces.

ASEE Maker Surveys

In the spring of 2016, the American Society for Engineering Education (ASEE) distributed an online survey to engineering deans and engineering technology deans and department chairs. The survey consisted primarily of a series of open-ended questions that asked respondents to define Making, asked them to describe Making activities at their universities, asked how Makerspace(s) are managed at their universities, and inquired about the perceived student outcomes they attribute to Making. The online survey was included in a link in an email sent by the chair of ASEE's Engineering Deans Council and the chair of ASEE's Engineering Technology Council. The surveys were distributed via engineering and engineering technology listservs managed by ASEE. The engineering deans' listserv has 320 members and the engineering technology dean or department chair listserv has 90 members. To be a member of a listserv, one must work at a school that is an institutional member of ASEE and serve in the capacity of an engineering dean or engineering technology dean or department chair. ASEE institutional members must be an engineering school or engineering technology school or department that pays dues to ASEE and has at least one ABET-accredited undergraduate engineering or engineering technology program and/or a graduate engineering program.

The survey received 93 responses: 64 identified as coming from engineering deans, 13 identified as coming from engineering technology deans or department chairs, and 16 identified as "other." Those who identified as "other" were forwarded the email from an engineering dean or engineering technology dean and asked to complete the survey. "Other" includes Maker lab directors, associate deans, and faculty who are knowledgeable about Makerspaces in their universities. To simplify our analysis, we re-coded the "other" respondents as either engineering or engineering technology, and came up with 77 responses from engineering and 16 from engineering technology. The response rate to the surveys was 24 percent for engineering deans and 18 percent for engineering technology deans and department chairs. The survey responses should not be viewed as representative of Maker activities for all engineering and engineering technology schools nationally, but should instead be seen as examples from engineering and engineering technology schools that engage in Maker activites. They also represent the views and opinions of engineering deans and engineering technology deans and department chairs that have incorporated Making in their programs and their views about Making.

We distributed a separate survey to several organizations that promote Making, including the MakeSchools Alliance, the Association of Science-Technology Centers (ASTC), Maker Ed, the National Science Foundation, Kippworks, LOLSpace, Exploratorium, MIT Media Lab, Idea Builder Labs, Hackaway.io, Children's Museum of Pittsburgh, Institute of Museum and Library Sciences, Idaho STEM Action Center, Digital Harbor Foundation, Tech Toybox, National Instruments, New York Hall of Science, NationofMakers.org, REM Learning Center, Digital Promise, NYSCI Maker Space, Big-Brained Superheros Club. We made arrangements for them to send out the survey via email or social media, or to post it to their website. We wanted to understand what those who engage in Making outside of engineering and engineering technology schools and departments think about Making, how their Makerspaces are financed and managed, and how their experience with Making could be used by engineering deans and engineering technology deans and department chairs to engage and attract new students. We received 21 responses. Eighteen respondents were located at academic institutions (16 at universities and two at K-12 institutions). One was at a museum and one was at a public library. Three respondents at universities indicated that their Makerspaces were associated with a college of engineering. In this document, we make a distinction between respondents to the survey sent to deans and department chairs and the "non-engineering academic Maker community" of respondents to the other survey. Our thinking is that engineering and engineering technology is part of the academic Maker community, and our intention with the survey sent to organizations that promote Making was to understand Making from the perspective of those who are not in engineering or engineering technology.

Our intention with the surveys was to:

- Use responses to create a conceptual understanding of Making.
- Document how organizations in the non-engineering academic Maker community and universities manage Makerspaces.
- Document how organizations that house Makerspaces engage the public with those spaces.
- Document perceived positive student outcomes that engineering and engineering technology deans attribute to Making.
- Document ideas from the non-Engineering academic Maker community as to how engineering and engineering technology programs could use Making to improve student retention and engage new student populations.
- Present the results of the surveys in a visually appealing and easy-to-understand way.

What is Making?

As noted in the introduction, no formal definition of Making exists. When we first conceived of this study, one of the purposes was to develop a general conceptual understanding of Making identified by the three groups. We were curious as to whether respondents from the non-engineering academic Maker community would conceive of Making in the same way as engineering deans and engineering technology deans and department chairs. We also wanted to learn whether engineering deans held similar views of Making to those of engineering technology deans and department chairs, given engineering's traditional emphasis on design and engineering technology's traditional emphasis on hands-on work.

In the surveys, we asked all recipients to define Making, although with engineering deans and engineering technology deans and department chairs we posed the question by asking what Making means to them. Most respondents provided two to three sentences articulating the more salient aspects of Making for them, rather than a complete definition.

Here are some illustrative examples:

A response from an engineering dean: "Making is applying design thinking in practice, lo-fi and rapid prototyping, building and testing. Typically, Making is entrepreneurial in nature, driven by the goal to experiment and explore, in contrast to more systematized and controlled manufacturing."

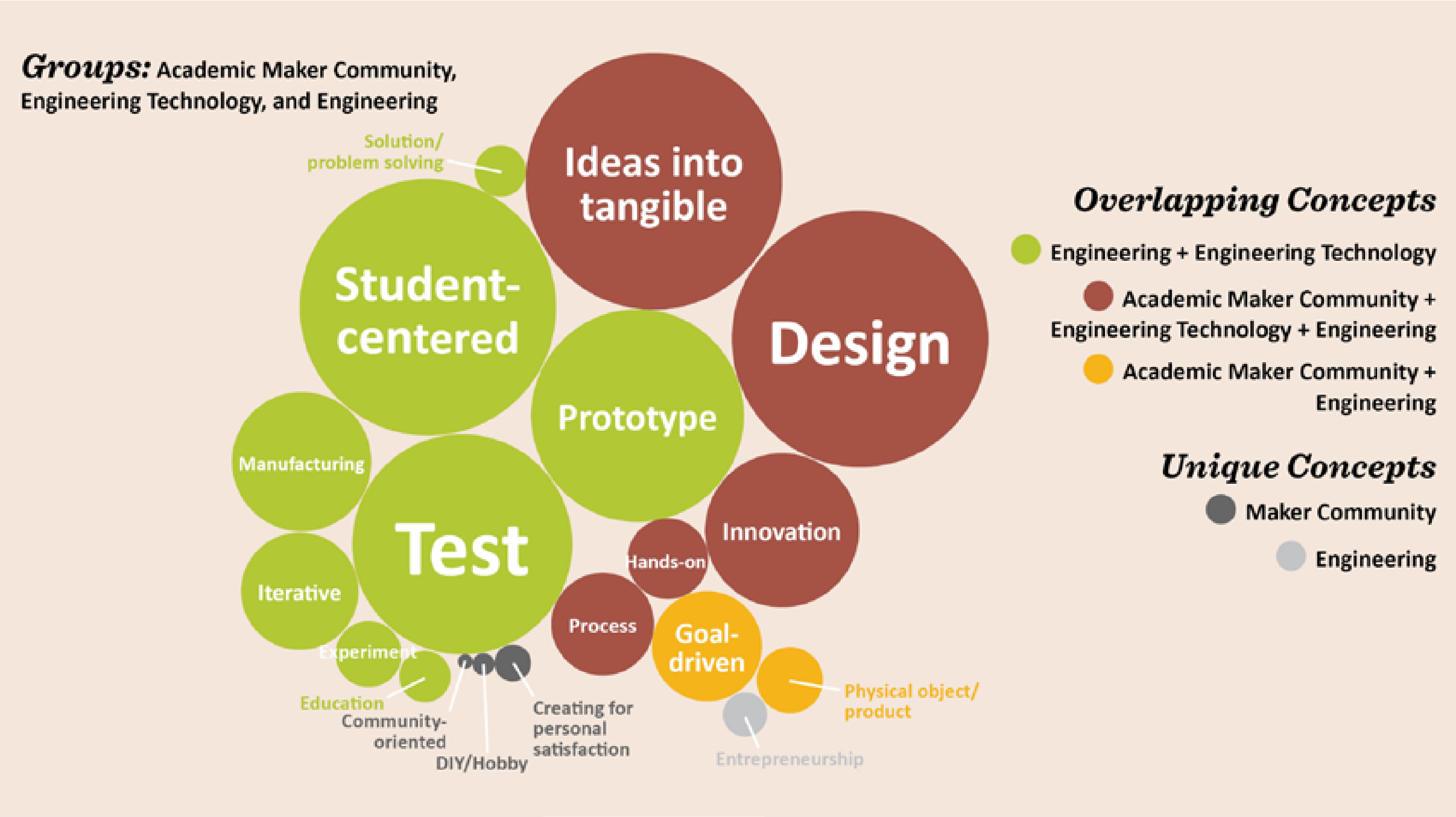
A response from an engineering technology dean or department chair: "Hands-on experience with design and fabrication of 'objects' across dimensions ranging from the nanoscale to macroscale."

A response from a non-engineering academic Maker community member: "Making is a term, used in its broadest sense, that implies you're creating something with materials and out of your own headspace. We often look to further refine Making as relying more on Do-It-Yourself (DIY) communities of folks who create original ideas and are engaged in a process and dialogues with their materials, tools, and community."

From survey responses, we looked for themes in words used and ideas expressed, and identified common terms and concepts from the responses. Words and concepts included: "Concept into Tangible Form," "Innovation," "Goal-driven," "Experiment," and "Process." The following bubble chart, *Figure 1. Core Concepts of Making* shows the frequency with which different terms or concepts were used in defining Making and illustrates how different groups that took the survey view Making. The larger the circle, the more frequently the term or concept was used.

All three groups generated several concepts of Making that overlap with the informal definitions of Making described in the introduction. Engineering deans and Engineering Technology deans and department chairs generated several Making concepts unique to engineering. The non-engineering academic Maker community generated a couple of Making concepts that overlap with the informal definitions of Making, but engineering and engineering technology deans and department chairs did not associate them with Making. Those concepts include DIY (Do-It-Yourself)/ hobby, community oriented, and creating for personal satisfaction.

Figure 1. Core Concepts of Making



The three groups—engineering deans, engineering technology deans and department chairs, and the non-engineering academic Maker community—offered many of the same terms and concepts in their definitions of Making, although there were some notable exceptions. Engineering deans associated Making with "Entrepreneurship." The non-Engineering academic Maker community associated Making with "Community-Oriented," "(DIY) Do-It-Yourself/Hobby," and "Creating for personal satisfaction." Engineering deans and engineering technology deans and department chairs associated Making with several engineering-related concepts that the non-Engineer Making community did not mention, including "Design," "Iterative," "Prototype," "Test," "Experiment," "Solution/ Problem Solving," and "Manufacturing." A number of engineering deans and members of the non-Engineering academic Maker community associated Making with "Goal-driven," while engineering technology deans and department chairs did not mention the term. It is possible that the respondents from the non-Engineering academic Maker community who used this term were themselves engineering-oriented and that other, non-engineering respondents from this community were not.

All three groups associated Making with many of the same terms and concepts, including "Design," "Hands-on," "Ideas into Tangible," "Process," and "Innovation." We found that the overlapping concepts associated with Making among the three groups had more in common with the definitions of Making in the literature than did the concepts identified only by engineering deans and engineering technology deans and department chairs. For example, terms used to define Making in the literature include "creating, producing, crafting, shaping, tinkering, composing, and building" (2014, Larson, p. 1); and Making as a "class of activities focused on designing, building, modifying, and/or repurposing material objects, for playful or useful ends, oriented towards making a 'product' of some sort that can be used, interacted with, or demonstrated" (Martin, 2015, p. 31).

Conceptual Understandings of Making

We had hoped to arrive at a single conceptual understanding of Making by synthesizing the definitions of making among the three groups. While there was a lot of overlap among engineering deans, engineering technology deans, department chairs, and non-engineering academic Maker community members, there were enough differences among the three groups that we settled on three conceptual understandings.

A conceptual understanding of Making for engineering deans:

Making is a goal-driven process. The goal of Making is to take a concept or idea and create it in a material form. The end product of Making is discovered through a series of iterations—creating prototypes, testing, and improving—until what is produced sufficiently adheres to the original concept or idea; or, through fortuitous serendipity, something is created that was not originally envisioned but is useful.

A conceptual understanding of Making for engineering technology deans and department chairs is nearly the same as the conceptual understanding for engineering deans, except that Making as "goal-driven" was removed:

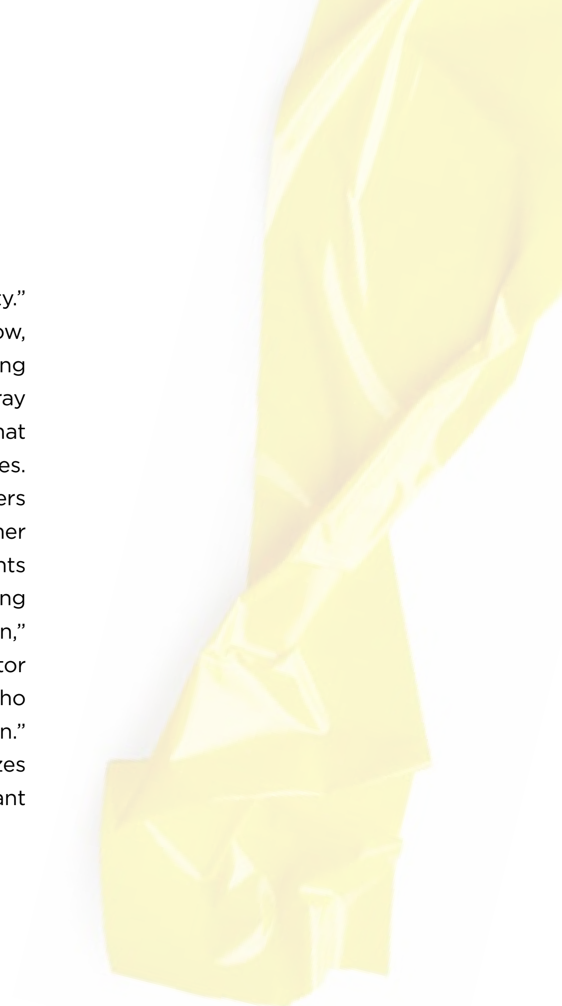
Making is to take a concept or idea and create it in a material form. The end-product of Making is discovered through a series of iterations—creating prototypes, testing, and improving—until what is produced sufficiently adheres to the original concept or idea; or, through fortuitous serendipity, something is created that was not originally envisioned but is useful.

A conceptual understanding of Making for the non-engineering academic Maker community is:

Making is the act of creating, taking an idea and using one's hands or tools to turn the idea into material form. A goal of Making is personal satisfaction and fulfillment.

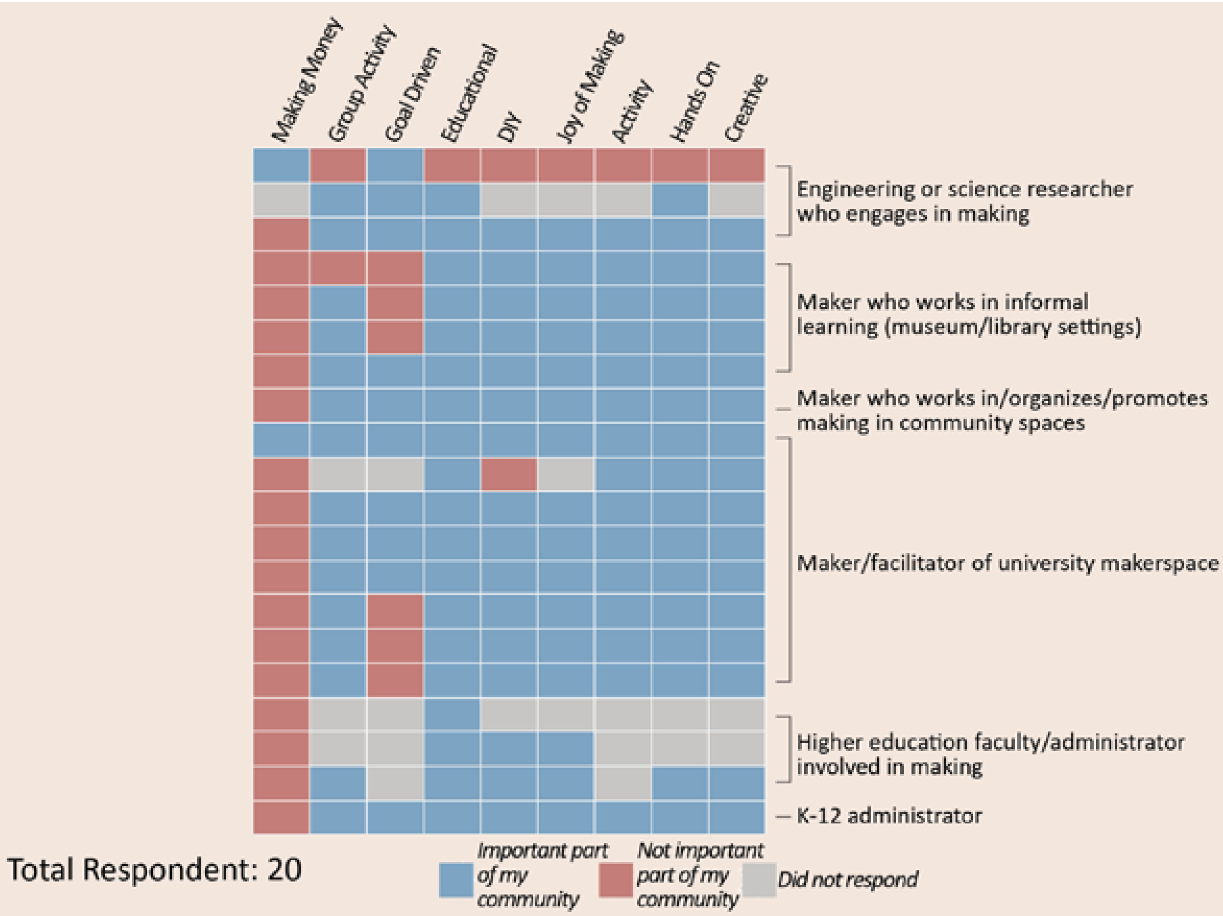
The conceptual understandings of Making are similar but differ in some important ways. Making within the context of engineering and engineering technology is more about taking an idea and using engineering processes to transform ideas into material form, while Making within the non-Engineering academic Maker community focuses on the act of creation and the sense of fulfillment that comes from creating. We believe the conceptual understanding of Making reflect the most important aspects of Making for each group. Engineering deans and engineering technology deans and department chairs focused on design, process, and manufacturing, all of which are used by engineering and engineering technology schools to apply what students have learned and to engage students in hands-on activities related to their academic pursuits. The non-engineering Academic Maker community, on the other hand, viewed Making as DIY (Do-It-Yourself)/a hobby, as community oriented, or as creating something for personal satisfaction.

To understand different groups within the non-engineering academic Making community and how they might view Making differently, we asked respondents from this community to sort terms that are associated with Making, including terms like "goal-driven," "creative," or "DIY." Members of the non-engineering academic Maker community were asked to



designate each term as "part of my Maker community" or "not part of my Maker community." As shown in *Figure 2. Academic Makers and Making Community Characteristics* below, blue boxes indicate that respondents designated that term as part of their Making community; orange means the term was not part of their Making community; and gray means the respondent did not designate that particular term. The heat map shows that most respondents held similar views of Making, though with some important differences. Two of the respondents who identified themselves as engineering or science researchers who engage in Making think of it as goal driven and do not associate Making with other concepts like "creative," "activity," "joy of making," and "DIY." Also, two of the respondents who identified themselves as higher education faculty/administrators involved in Making did not designate certain terms, including "creative," "hands-on," "activity," "goal driven," and "group activity." Half of the respondents who reported being a manager/facilitator of a university Makerspace, and almost all respondents who reported being a Maker who works in informal learning (museum/library settings) did not view making as "goal driven." Only two respondents associated Making with making money. The heat map emphasizes the point that many concepts about what is Making are shared, but there are important differences in how Making is viewed.

Figure 2. Academic Makers and Making Community Characteristics



The Importance of Housing a Makerspace

We found that whether or not a school has a Makerspace or multiple Makerspaces had a bearing on the incorporation of Making into an engineering or engineering technology program, as well as on observed positive student outcomes attributed to Making and the type of Making activities in the school or department.

As we looked through the survey responses to the engineering and engineering technology Maker survey, we noticed that the responses about how many Makerspaces are located on a campus could be divided into three groups: none, one, or multiple. A total of twenty-two (twenty-four percent) engineering deans and engineering technology deans and department chairs reported having no designated Makerspace on campus. A total of twenty-nine (thirty-one percent) engineering deans and engineering technology deans and department chairs reported a single, central Makerspace on campus. A total of forty-one (forty-five percent) engineering deans and engineering technology deans and department chairs reported multiple Makerspaces on campus, housed within multiple departments, schools, libraries, research centers, or any combination of departments, schools, libraries, or other locations.

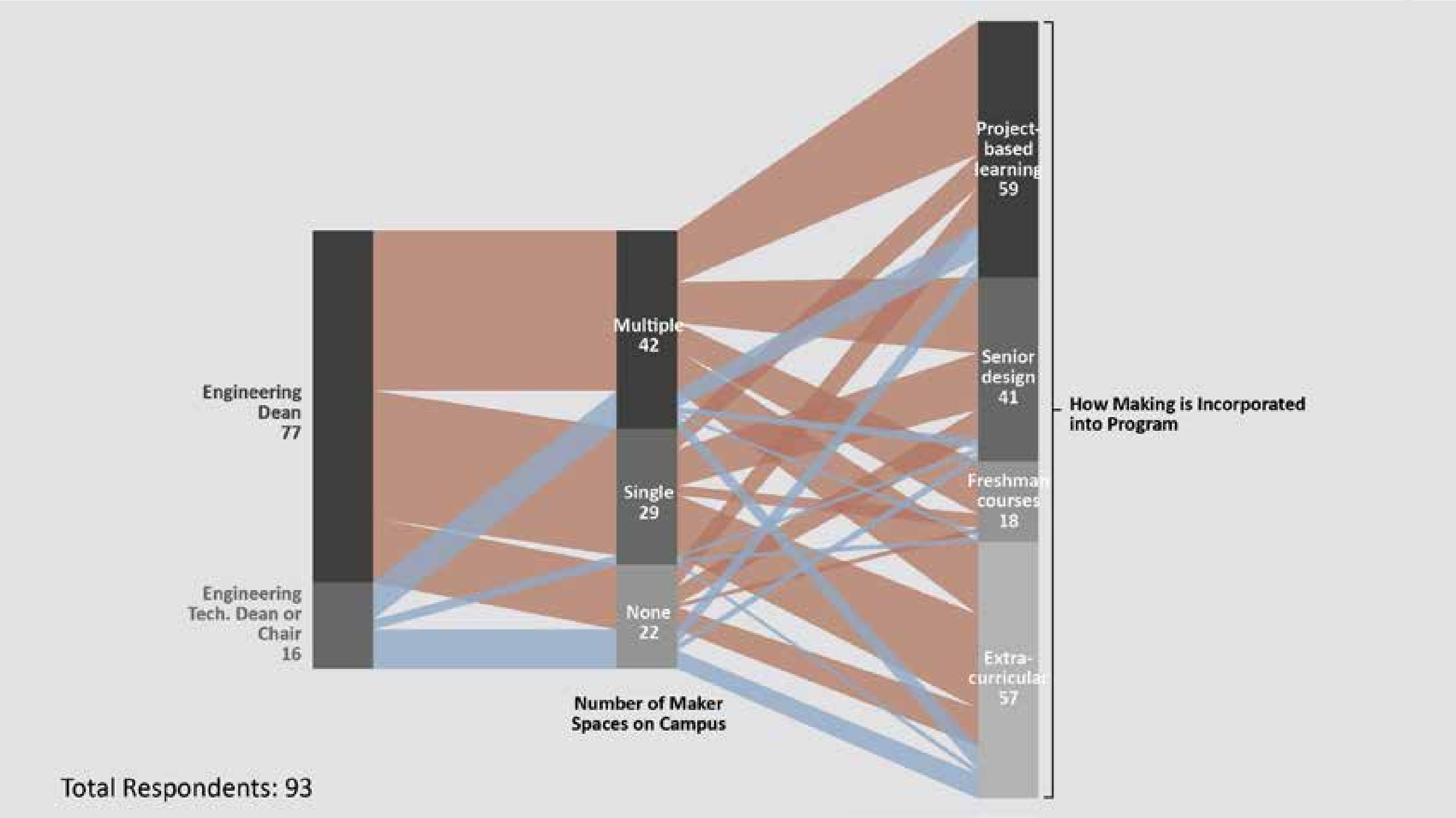
Almost all engineering and engineering technology deans and department chairs reported having activities in their programs that could be classified as making. Deans and department chairs at schools that reported having multiple Makerspaces on campus also reported incorporating Making into engineering and engineering technology programs more frequently than did those who reported a single Makerspace or no designated Makerspace.

We asked engineering and engineering technology deans and department chairs if they had activities in their programs that could be classified as Making (e.g. project-based learning, prototyping). Almost all respondents (89 out of 93) responded "yes"—Making activities were incorporated into their programs. Of the four respondents who had not incorporated Making activities into their programs, two said they were in the process of doing so. The third said they had Maker labs that students used, but the school hadn't incorporated Making into its program. The fourth respondent did not answer the question.

Respondents typically mentioned four ways in which schools incorporated Making into their programs, as shown in Figure 3, following. Most frequently noted was project-based learning (sixty-three percent or 59 out of 93 respondents), followed by extracurricular (sixty-one percent or 57 out of 93 respondents), senior design (forty-five percent or 41 out of 93 respondents), and freshman courses (nineteen percent or 18 out of 93 respondents). Incorporation of Making into engineering and engineering technology programs was most frequent among deans and department chairs who reported having multiple Makerspaces on campus. Those who reported a single Makerspace on campus reported less frequently that they had integrated Making into their programs, but more frequently than those who reported having no Makerspace on campus. Those who reported a single Makerspace mentioned extracurricular Making activities more often than did those with multiple Makerspaces on campus or no Makerspace. *Figure 3. Ways that Schools Incorporate Making into their Programs,* following, shows the number of engineering deans and engineering technology deans, the number of Makerspaces they reported, and the frequency by which they incorporate Making into their program, most frequently, through project based learning.

Examples of project-based learning included prototyping, 3D modeling, 3D printing, laser scanning, and real-world activities with industry mentors. In the context of this

Figure 3. Ways that Schools Incorporate Making into their Programs



survey, project-based learning is best described as the incorporation of iterative engineering design principles into coursework. This is usually accomplished through 3D modeling or 3D printing that allows for design, prototyping, and testing, or real-world, goal-oriented activities like a robot competition or working with industry mentors on a project.

Extracurricular activities were the second most frequently mentioned way in which Making is incorporated into engineering and engineering technology programs. Examples of extracurricular activities include clubs that include Making activities like *Engineers Without Borders,* in which students pursue solutions to real-world problems, robot competitions, and designated Maker lab spaces where students can design and create.

Many examples of Making incorporated into freshman courses fit traditional project-based learning. For instance, an engineering technology dean described an *Introduction to Electronics* class where freshmen build a power supply, and a construction class where students build a small 6x6x7 foot house and donate it to a charitable organization. Another example from an engineering dean was a bioengineering course in which freshmen visit clinical labs, get ideas for improving the medical processes, develop prototypes, and enter a competition called *Bench-to-Bedside.* Other examples of Making in freshman classes went beyond traditional coursework. These included *Engineering Projects In Community Service (EPICS)*—teams of students that partner with non-profit and educational organizations to design, build, and deploy systems over several years. Another example was a freshman course on creativity jointly taught by engineering and arts instructors.

Senior capstone projects are examples of project-based learning that require students to use what they learned during engineering and engineering technology

Engineering deans and engineering technology deans and department chairs who reported one or multiple Makerspaces on campus more frequently reported Making incorporated into freshman courses and senior design courses than those who reported no Makerspace on campus. Those who reported a single Makerspace on campus more frequently reported Making as an extracurricular activity than those who reported none or multiple Makerspaces.

classes to create something, often utilizing a Makerspace. Most senior capstone projects described in the survey require students to start with a concept and develop a design, create a prototype, test the prototype, and finish with an end product. This process essentially follows the conceptual understanding of Making we identified from engineering and engineering technology. Some examples of senior capstone projects that incorporated Making engaged seniors in solving problems for industry. Others included making products within particular constraints and design elements. One respondent noted that "projects often culminate with a working prototype and our design challenges (are intended) to inspire students to make time to be creative and take a chance at Making."

Descriptions of Makerspaces at Engineering Colleges and Engineering Technology Schools and Departments, and How the Spaces are Used

Seventy-six percent of engineering deans and engineering technology deans and department chairs reported having a Makerspace or Makerspaces in their school or department, but we think the percentage might be higher due to differences in what respondents call a Makerspace. We noted similarities in equipment between a Makerspace and a machine shop. Some respondents who reported they had no Makerspaces on campus would go on to describe Making activities that students undertake in machine shops, while others described machine shops but called them Makerspaces.

We did not find differences in how Makerspaces are used between engineering deans and engineering technology deans and department chairs who reported one central Makerspace and those who reported multiple Makerspaces. Nor did we find generalized differences in how those with a single Makerspace or multiple Makerspaces described their Makerspace(s). Makerspaces take on a variety of sizes, equipment, and uses. Makerspaces varied from 500 square feet to 20,000 square feet. One respondent reported 40 Makerspaces taking a total of 125,000 square feet and used for all types of Maker activities: "class projects, research projects, hobby/personal making, teams/clubs projects, and other extracurricular (e.g. social events, Make-a-thons, and hack-a-thons)." Many respondents described the types of equipment available in the spaces, which we tabulated and present in Table 1. The most frequently mentioned devices were 3D printers and scanners, followed by machine-shop tools, fabrication tools, design tools, laser cutters, electronics, and—though least often mentioned—automatic and robotic systems.

Table 1: Equipment Available in Makerspace(s)

3D printers and scanners	29
Machine shop (milling, cutting, welding, CNC)	25
Fabrication (wood, plastic, metal, vinyl, textiles, ceramics, sewing, painting, soldering, power tools)	16
Design suite (CAD, PCB, Arduino, software, visualization and simulation systems)	15
Laser cutter	9
Electronics (circuit board fabricators, batteries)	5
Automatic and Robotic Systems	4

Spaces were used by students for engineering and engineering technology classes, for independent projects, and by Maker-related clubs. For example, a respondent reported, "The Makerspace(s) are used as open student creation space as well as to directly support the curriculum by hosting classes and labs." A second respondent reported that the site "supports the MakerLab club (student projects) and Make-It-Happen (MIH) program (independent study courses). Any student can join the club, pass safety training, propose a project to work on, and work in the space. The space is open most days from 10 a.m. to midnight." Another reported, "Introduction to Engineering courses and senior design courses are held in the space. The space has meeting areas (tables, laptops on carts, walls to write on, and display screens), a 3D printing and laser-cutting lab, a Computer Numerical Controlled (CNC) lathe and milling machine lab, small electronics processing bay, a small tooling (woodwork, etc.) bay, and an area for light work (table, small tools). Students can work on projects at any time. Formal classes [are] held mostly on Tuesday through Thursday."

A few respondents described their Makerspaces as open to anyone; for example, one respondent reported that "currently the Makerspace has basically 3D printers in it. The space can be reserved by anyone, on campus or the public, to use. If they do not know how to use the equipment, they are trained and then are allowed to reserve the space when they need to use it. There is also a mechanism which will track and bill the person using the space for the materials that they use."

Making in the Curriculum and Student Outcomes

Engineering deans and engineering technology deans and department chairs at schools that possess multiple Makerspaces reported improved student outcomes attributed to Making more frequently than did those with a single Makerspace or no designated Makerspace on campus. Regardless of the number of Makerspaces, almost all engineering deans and engineering technology deans and department chairs reported incorporating Making in their curricula.

Twenty-one respondents (twenty-three percent) who reported that they did not have a Makerspace were nonetheless incorporating Making in their curriculum. For example, one engineering technology dean on a campus without a Makerspace reported:

"We have a class on prototyping. We also have manufacturing classes in engineering technology where students must come up with the idea of a new product and then make it in our machine shop. Seniors solve problems for industry, sometimes by making test stands or making a new part."

An engineering dean without a Makerspace on campus reported:

"Yes, many courses have 'making' as part of projects, both individual and group."

Consistently, engineering deans and engineering technology deans and department chairs on campuses without Makerspaces reported integrating making into their programs.

A high proportion of respondents who reported integrating Making into their curricula also reported that Making enables engineering and engineering technology to attract a more diverse group of students. However, when it came to student outcomes like grades, student performance in class, and retention, respondents with one or more Makerspaces at their schools more frequently reported improved student outcomes than did those with no designated Makerspace.

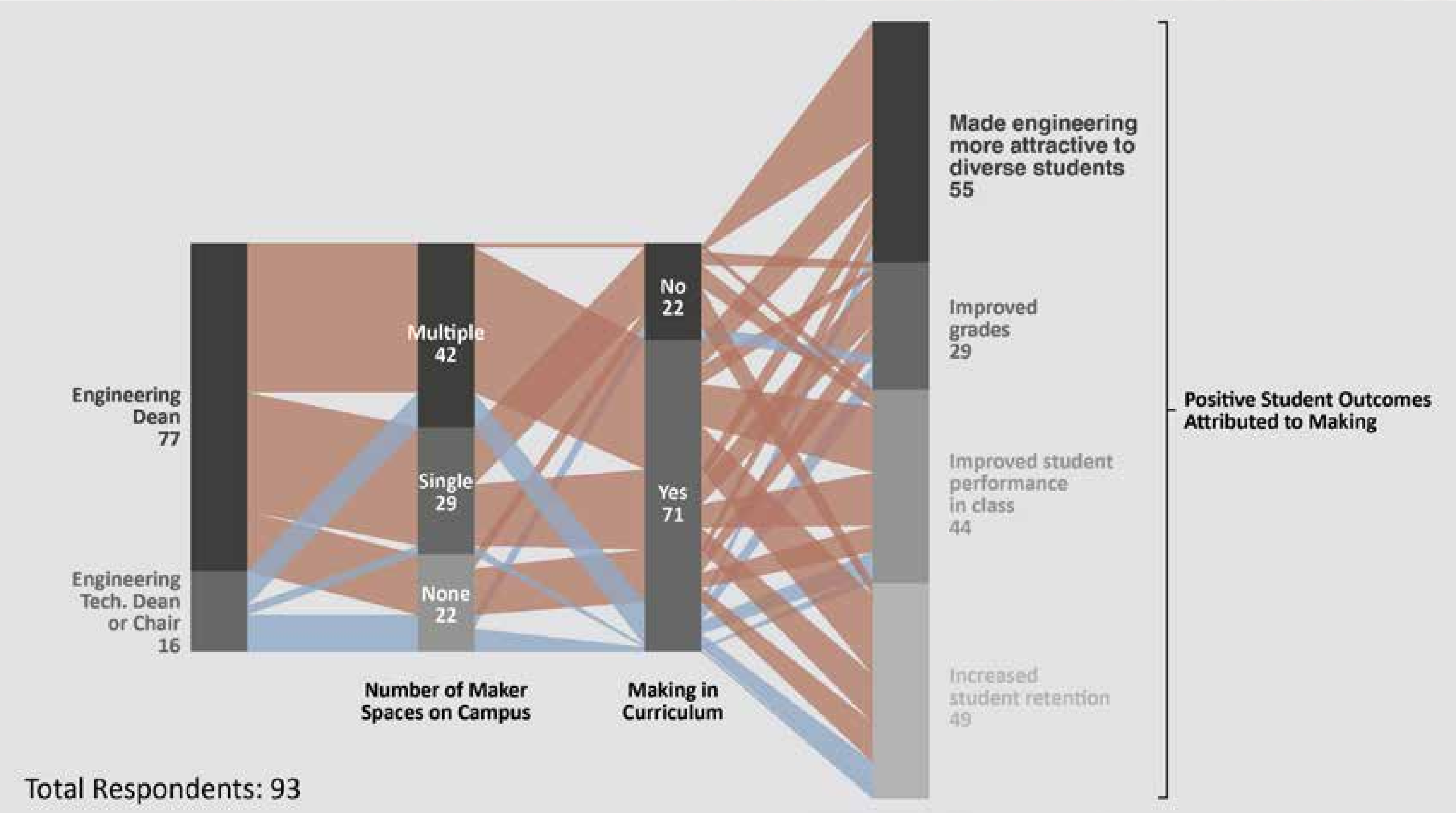
As shown in the following alluvial diagram, *Figure 4. Making in Curriculum: Observed Positive Outcomes Attributed to Making,* seventy-one (ninety percent) engineering deans and engineering technology deans and department chairs reported having integrated Making into their curricula, regardless of whether their campuses had a single or multiple Makerspaces or none at all. The diagram also shows that engineering deans and engineering technology deans and department chairs with a single or multiple Makerspaces on campus more frequently reported improved student outcomes attributable to making. The percentages are not shown in the diagram, but ninety percent of deans and department chairs with multiple Makerspaces on campus reported that their school or department used Making in its curriculum. Sixty-two percent of those with one Makerspace on campus reported that their school or department used Making in its curriculum. A higher percentage (sixty-eight percent) of engineering deans and engineering technology deans and department chairs with no Makerspace on campus reported that their school or department used Making in its curriculum.

The most frequently observed positive student outcome attributed to Making was that it made engineering attractive to a more diverse group of students (fifty-nine percent or 55 out of 93 respondents). This was followed by increased student retention (fifty-three percent or 49 out of 93 respondents), improved student performance in class (forty-seven percent or 44 out of 93 respondents), and improved grades (thirty-one percent, or 29 out of 93 respondents). Engineering deans and engineering technology deans and department chairs with multiple Makerspaces on campus reported improved student outcomes more frequently than did those whose campuses had a single Makerspace.

Another way to view the data is to compare those who reported having incorporated Making into their curricula with those who had not. As shown in the previous alluvial

Engineering deans and engineering technology deans and department chairs who reported incorporating Making into their curriculum more frequently reported observing positive student outcomes than those who did not report incorporating Making into the curriculum. Engineering deans and engineering technology deans and department chairs who reported a single or multiple Makerspaces on campus more frequently reported positive student outcomes than those who reported no Makerspace on campus.

Figure 4. Making in Curriculum: Observed Positive Outcomes Attributed to Making



diagram, *Figure 4. Making in Curriculum: Observed Positive Outcomes Attributed to Making,* a higher proportion of those who incorporated Making in their curricula consistently reported higher student outcomes attributable to Making. These outcomes included increased student retention, improved student performance in the classroom, improved grades, and attraction of a more diverse group of students.

Makerspaces and Student Engagement

Following are examples of increased student engagement or access to engineering or engineering technology reported by engineering deans and engineering technology deans and department chairs. Whether or not a school has a Makerspace is reflected in the kind of Making activities reported at the school.

We asked engineering deans and engineering technology deans and department chairs to provide an example from their schools or departments of how Making has increased student engagement or access to engineering or engineering technology. Forty-two percent of respondents provided examples. We grouped the examples according to whether a school had no Makerspace, a single Makerspace, or multiple Makerspaces to see if there were any discernable patterns in how engineering deans and engineering technology deans and department chairs responded based on their numbers of reported Makerspaces.

Only 18 percent of respondents reported having no designated Makerspaces at their schools. The types of Making activities these respondents described were Making opportunities outside the university. For example, one respondent reported that "students in mechanical engineering have been involved in a design contest organized by NASA every year for the past several years. Last year, a team [of] undergraduate students from mechanical engineering won 1st place [as the] top design team at the NASA TSGC Design Challenge 2015." Another respondent reported, "We are currently working with the student STEM Club to make an electric vehicle as part of Electrathon, a national competition to design, build, and race electric vehicles. It will be designed, built, tested, and used by the students in a multi-disciplinary environment."

Of the 45 percent of engineering deans and technology engineering deans and department chairs with a single Makerspace on campus, examples of activities were split between Making as an extracurricular activity and Making incorporated in the curriculum. These included: "The college utilizes its Making curriculum and space effectively through its Senior Design Project program, which encompasses all six majors in the college. Students participate in projects ranging from a few weeks to an entire year." Another respondent wrote that "our mechanical engineering is extremely popular because of its emphasis on experiential learning in the introductory course, the instructors start the term by surveying students to ask about their experience in using machine tools, power tools, even hand tools; in using design software, etc. The (anonymous) results are then shared with the class, and it shows the students very directly that many of them have zero experience. To the student who thinks he or she is alone in being unskilled, it tells a very different

When asked for examples of increased student engagement or access to engineering attributed to Making, engineering deans and engineering technology deans and department chairs who reported having no Makerspace on campus reported Making activities that take place outside of the university, such as national design competitions. Those who reported a single Makerspace or multiple Makerspaces on campus reported a variety of extra-curricular Maker activities and Making incorporated into classroom activities. Those with multiple Makerspaces on campus were more detailed in their descriptions of activities than those who reported a single Makerspace on campus.

story. Our enrollments are now more than 40 percent women in engineering, and this course, and this approach, are important contributors."

The longest and most detailed responses came from engineering technology deans and department chairs whose schools had Makerspaces distributed across multiple locations. This group represented 52 percent of respondents. Their descriptions of how these spaces were used were split evenly between Making as an extracurricular activity and Making incorporated in the curriculum. They also offered examples of increased student engagement or access to engineering or engineering technology.

Here are several examples they provided of programs that include Making:

> "Our GoldShirt Program is directed at talented and motivated but underprepared students who would not otherwise have been able to enter the college as direct admits. The GoldShirt curriculum includes a freshman projects course centered on Making and teamwork. This program has provided significant increases in student engagement and access to engineering, helping to triple the number of underrepresented minority students in our college."
>
> "Making is vertically integrated with the curriculum in the College of Engineering and incorporated into numerous courses in the College of Arts & Architecture, Earth & Mineral Sciences, Information Sciences & Technology, Health & Human Development, Liberal Arts, and Business. Engineering courses leverage Making throughout the undergraduate career in nearly every discipline and at the graduate level, and we are continually identifying new ways to engage students in the Maker culture earlier in their college experience."
>
> "Many of our most engaged students are heavily involved in Making. We have hundreds of such examples. These students may spend 20-80 hours per week on their project. Sometimes their grades suffer a bit, but they pick up an amazing set of skills, including leadership, and they produce incredible results. These students are scooped up by industry."
>
> "Many students in ENGR 202 learn about the various pathways to an engineering degree. Students become aware of, and interested in, other engineering disciplines. Students are more interested in joining engineering project teams (Formula SAE, etc.) earlier in their studies." And,
>
> "The MakerWorkshop at our university is a student-run Makerspace with technology that spans from hand tools, to 3D printers, laser cutters, waterjet, and lathe. This facility, within the last year, has enabled 500+ students to have after-hours access to this technology (and peer mentorship), which we find is key as our studies indicate that this is when students most need access to these technologies (only about 7 percent of our students find access between 8 a.m. [and] 4 p.m. to be convenient).

Non-Engineering Academic Maker Community Survey Results

We distributed a separate survey to several organizations that promote Making, including the MakeSchools Alliance, ASTC, Maker Ed, and Make Spaces and arranged for them to send out the survey via email or social media or post it to their website. We wanted to understand what those who engage in Making outside of engineering and engineering technology schools and departments think about Making, how their Makerspaces are financed and managed, and if they had thoughts about how their experience with Making could be used by engineering deans and engineering technology deans and department chairs to engage and attract new students. We received a total of 21 responses.

A majority (18) of respondents to the survey were at academic institutions (16 at universities and two at K-12 schools). One was at a museum and one was at a public library.

Location of Makerspace

We asked survey-takers where their Makerspace(s) were located. Twenty Makerspaces occupied a single location, although a few of the spaces were described as occupying multiple floors or rooms in the same building. Makerspaces were housed in "academic buildings," "campus libraries," "a museum," and "a public library."

Role of the Makerspace Within the Organization

Organizations reported that their Makerspaces were principally used for community engagement and outreach. The space's purpose, as one respondent put it, was "to provide the community with opportunities for: reaching curricular goals through more complex hands-on projects, cross-age mentoring, peer mentoring and bringing together students from neighboring schools, and large-scale community engagement activities." Another organization reported that its Makerspace "is dedicated to hands-on learning and cultivating valuable experiences in the community through making." A third described it "[as] an area to bring together the tools, expertise, and the community." The focus of Makerspaces bringing together the community differed from the how many engineering deans and engineering technology deans viewed the role of the Makerspace(s) in their schools, which included skill building, student engagement, and hands-on learning. Generally, using a Makerspace for direct community engagement was not reported as a stated goal for Making by engineering deans and engineering technology deans and department chairs, although Makerspaces were used to engage engineering and engineering technology students and at times students engaged with the local community as part of a Maker project.

How the Non-Engineering Academic Maker Community Attracts New Members

Further exploring the theme of community engagement, we asked survey participants from organizations how they attract new members to Making. Typically, organizations arranged some sort of activity at the Makerspace, such as a tour or a class that demonstrates how the equipment in the Makerspace works, and then relied on word-of-mouth from attendees to recruit other interested community members to subsequent Making activities. Although less frequently reported, other organizations advertised via email or social media to attract new members. Placing Makerspaces in an easily accessible location and having an open-door policy also helped to attract members. In engineering programs, Making is not usually viewed as a way to attract new students to engineering, but rather to enhance classroom learning and engage students. It has, however, been used in some schools to attract underrepresented minority students to engineering.

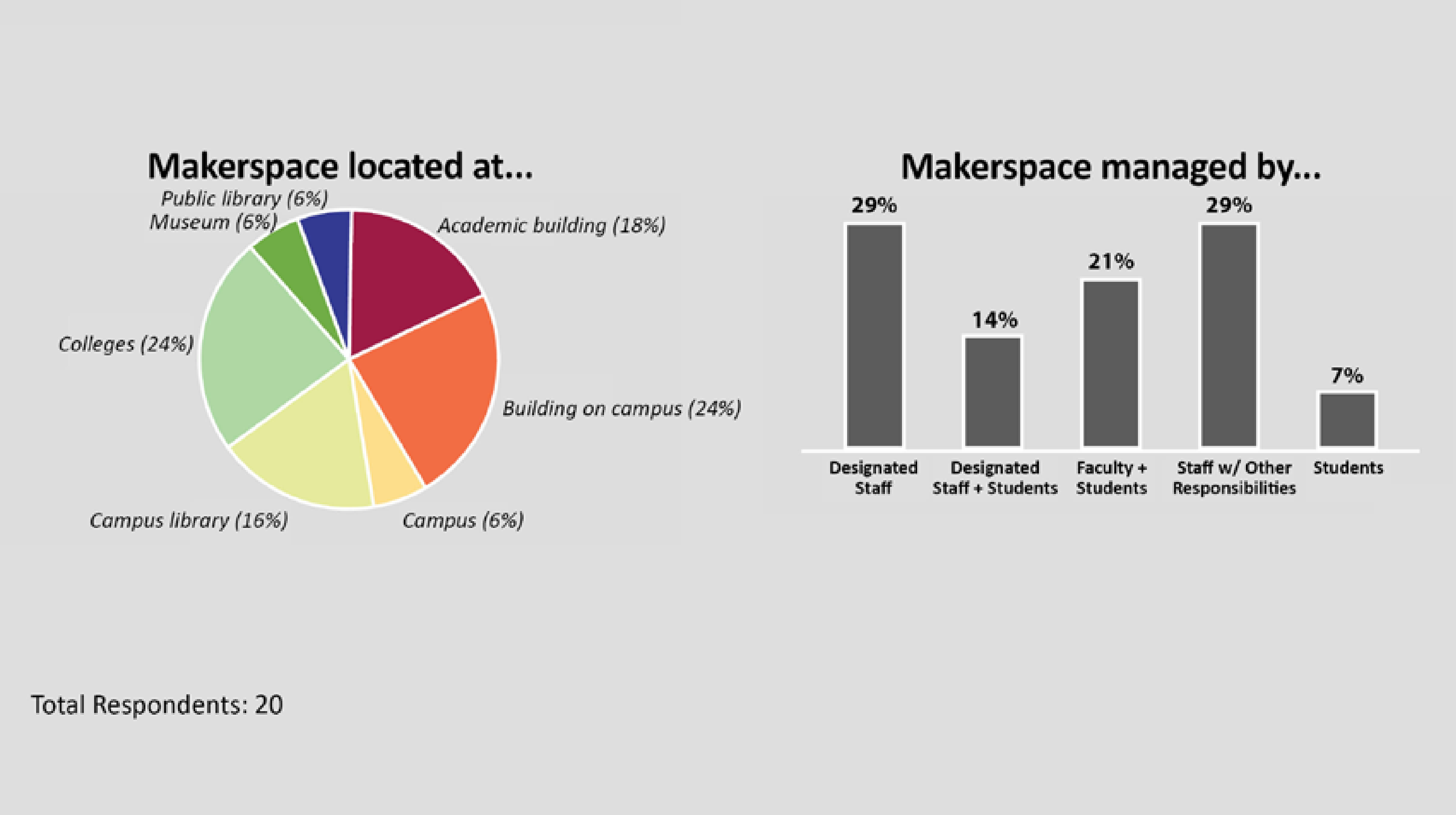
How Makerspaces are Managed

Whether housed at universities or at non-academic organizations, Makerspaces were managed by designated staff members or a combination of staff, faculty, and students in the unit or department where they were located. For example, if the Makerspace was housed in a library, it was managed by library staff; if it was in a museum, it was managed by staff in the education office at the museum. As shown in the following graphic, *Figure 5. Location and Management of Makerspaces,* different staffing combinations were used to manage the space. About a third of the responses stated that the Makerspace was managed by designated staff, or staff who were hired specifically to manage the space, and about a third of the responses stated that the Makerspace was managed by staff with other responsibilities; for example, librarians who check out library materials and also oversee a Makerspace, or education staff in a museum who also manage a Makerspace in the museum in addition to their other responsibilities. Thirty-five percent of the time the space was managed by designated staff and students or faculty and students. Seven percent of the time the space was managed by students.

Almost sixty percent of those who responded to our survey from the non-engineering academic Maker community reported that their Makerspace is managed by designated staff or by staff with other responsibilities who also manage the space (i.e., librarians who manage a Makerspace at a library, education museum staff who manage a Makerspace at a museum). Around a third of the Makerspaces are managed by a combination of designated staff and students or faculty and students. Less than ten percent of Makerspaces were managed by students alone.

Some examples of responses include: “[T]he space is managed on a day-to-day basis by a group of students with institutional and facilities support by certain electrical engineering department staff.”

Figure 5. Location and Management of Makerspaces



The space is managed by “faculty administrators and student volunteers with privileges based on skills and training.”

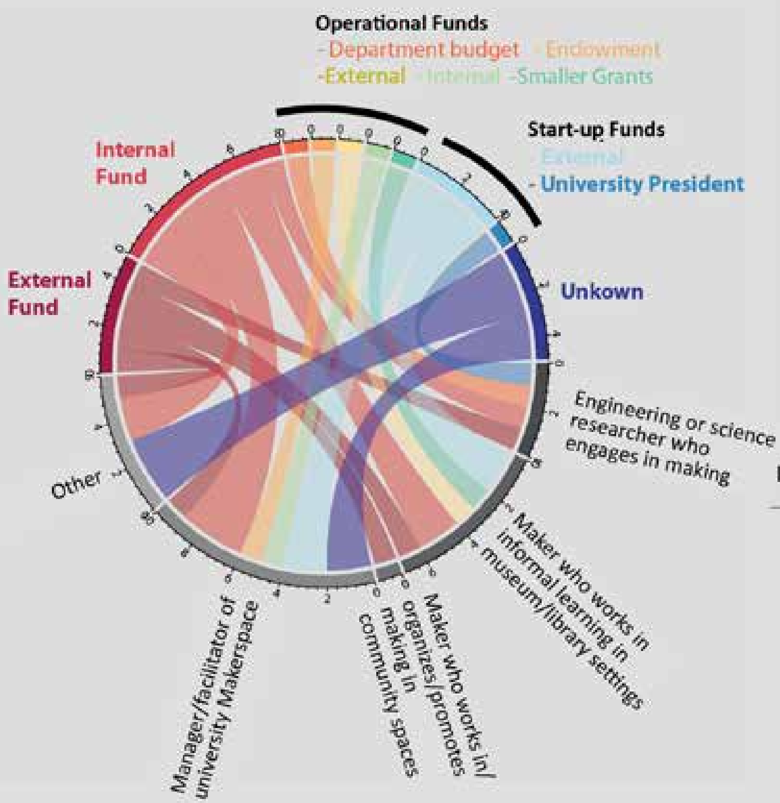
“We have two directors who manage the space with the support of the leading users. The super-users help manage the space, train, and supervise users.”

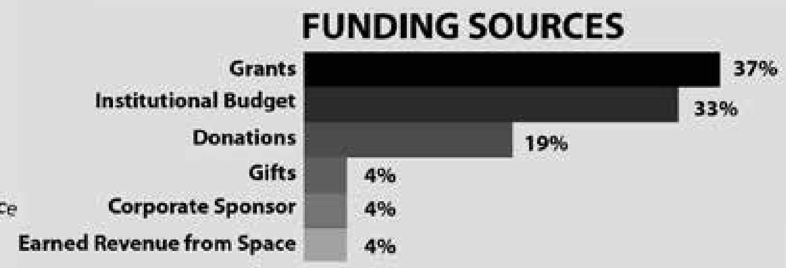
“The Makerspace is a university-wide effort, though it is led by the school of engineering. One faculty member, five staff, and a team of 35 student workers (filling about three FTE’s worth of time) manage the space.”

How Makerspaces are Financed

Most Makerspace construction was funded by external sources, including donations, grants, and corporate sponsorship, according to survey respondents. The funds for managing and maintaining the Makerspace usually came from a different source, such as separate grants and gifts, the institution’s budget, or funds generated from the space. For example, one respondent said “the Makerspace received corporate sponsorship to fund the capital construction, and ongoing funding comes from regular earned revenue and smaller corporate sponsorship of events.” Another reported that “the space was originally funded by a donation, and is now financed out of the library’s operating budget.” Of those who reported how their Makerspace was financed, just under half described a combination of sources, with start-up funds covered by one source and funds associated with managing and maintaining the space covered by a different source. About 20 percent reported that the spaces are funded by a combination of external funds, grants, gifts, and donations.

Figure 6. How Makerspaces are Financed





How Making Can be Incorporated into Engineering and Engineering Technology Programs to Improve Student Engagement and Reach New Student Populations

We asked survey participants if they had any thoughts about how Making could be incorporated into undergraduate engineering and engineering technology programs to improve student engagement and draw new student populations to engineering and engineering technology. Suggestions offered by respondents associated with university Makerspaces and libraries were similar to those made by deans of engineering and engineering technology schools and heads of departments. These suggestions were clustered around using hands-on Making activities to reinforce what students learn in the classroom, or using Making as an opportunity for students to engage in engineering processes to create things for the community.

For example, one respondent suggested that “the best ways to incorporate Making in undergrad engineering programs: Have design competitions that matter and that have real applications in the community. Partner with the local library or other organizations to build a solar car for outreach, or to design a book bike, a shed for a community garden, an outdoor art exhibition platform for the local art museum, an interactive sign for the local Makerspace, etc. Provide student groups with a budget and design criteria, have a group of diverse people from the community provide feedback (in the form of a constructive criticism), have students iterate the design, and then BUILD!”

Another responded stated, “I think it is very important for undergraduate programs to have a large student-directed hands-on component to both reinforce class material and motivate the students.”

And “I think that the opportunity to move through design cycles in a low-stakes and playful way could have a lot of benefit for first-year students; I think that having a low-barrier-to-entry space for creating prototypes can benefit all students.”

Another responded that “one might look at it and say how does engineering and engineering technology help people solve the great—and little—problems of our lives and the world. Often Makers are inherent engineers and technologists who have learned some deep craft knowledge in pursuit of something that specifically interests or is important to them. Thinking tools like ideation, design, iteration, etc. are about how to approach and solve a problem, and are critical to again solving issues of importance. Learning statistical modeling, computer programming, engineering physics and math, are all in support of tackling important problems and issues. Flipping the model to ‘how to make things to solve the problems of the world—and in your life’ might be an interesting start. And of course, encouraging (and requiring) people to think with their hands is a critical tool as well.”

Recommendations from the non-engineering academic Maker community to improve student engagement and attract new students to engineering mirrored Making activities reported by engineering deans and engineering technology deans and department chairs. Recommendations included using hands-on Making activities to reinforce what students learn in the classroom, or using Making as an opportunity for students to engage in engineering processes to create things for the community. Two K-12 teachers who responded to our survey also recommended outreach and engagement Maker activities that teach design principles and provide opportunities to introduce pre-college students to engineering.

We found that those who teach K-12 students had suggestions that went beyond what engineering deans and engineering technology deans and department chairs had reported they do. These instructors provided ways to engage and reach new student populations by engaging them in Making activities so they become familiar with Making and interested in engineering and engineering technology.

One respondent who works in K-12 wrote: “At both our high school and middle school, we employ design thinking methodologies. In our high school science classes, we emphasize the engineering design process and take particular notice of how the two are related, and again to the nature of science. We illustrate how the empathy piece is critical to a successful design in any realm, and with our entrepreneurship program we are working on ideas of prototyping. We feel the need for students to better understand that the first draft . . . should not be the final draft; or even anywhere close to a final product. I think this is the piece that could best enhance undergraduate programs.”

And, “I am teaching in a K-8 school and doing lots of professional development with K-12 teachers nationally. I am saying/introducing/using ‘engineering’ and related ‘engineering design process’ as a regular part of this work. The fact that students and their teachers are being introduced to the thinking dispositions of engineers when ‘engineering’ was barely in our vocabulary previously is HUGE for the engineering field. I have no doubt that we are now introducing many more students to the world of engineering as a future career, and consequently we will see undergraduate interest increase over the next 4-10 years.”

Comments such as these suggest that Making is a good way to introduce engineering design principles and that providing Making opportunities for K-12 students would serve to attract and retain a more diverse undergraduate population in engineering and engineering technology.

Summary and Final Thoughts

ASEE created and distributed two surveys about Making. One was sent to engineering deans and engineering technology deans and department chairs, and a second was sent to members of the "non-Engineering academic Maker community." The goal of the surveys were to gain a better understanding of Making at engineering and engineering technology schools and departments, of the views and value of Making from the perspective of engineering deans and engineering technology deans and department chairs, and of Making from the perspective of the non-Engineering academic Maker community and how organizations use, finance, and manage Makerspaces.

Conceptual Understandings of Making

We found that engineering deans and engineering technology deans and department chairs and the non-Engineering academic Maker community shared many of the same ideas about Making. The three groups associated Making with many of the same terms and concepts, including "design," "hands-on," "ideas into tangible," and "innovation." We found that the overlapping concepts associated with Making among the three groups had much in common with the informal definitions of Making identified in the literature.

But there were some important differences among the groups. The non-Engineering academic Maker community associated Making with "community-oriented," "(DIY) Do-It-Yourself/hobby," concepts and "creating for personal satisfaction." Engineering deans and engineering technology deans and department chairs associated Making with several engineering-related concepts that the non-Engineering academic making community did not mention, including "iterative," "prototype," "test," "experiment," "solution/problem solving," and "manufacturing." We attribute these differences to the varied ways in which Making is used. In engineering and engineering technology, Making is used to provide ways for students to apply what they learned in class, offer students opportunities to work together on problem-based learning, and to encourage self-directed, creative projects. In the non-Engineering academic Maker community, Making is a way to engage the community in creating something.

The Importance of Housing a Makerspace

Deans and department chairs from engineering schools and engineering technology schools and departments reported having no Makerspace, one Makerspace, or multiple Makerspaces. We found a relationship between greater access to Makerspaces and both the incorporation of Making into curricula and reported positive student outcomes attributed to Making. Survey respondents who reported having multiple Makerspaces on campuses more frequently reported that Maker activities were incorporated into their program and reported positive student outcomes attributed to Making than did those with a single Makerspace or no Makerspace on campus.

Community Engagement and Attracting New Members to Engineering through Making

Participants who completed the "non-Engineering academic Maker community" survey reported that the role of the Makerspace and associated activities within their organizations was principally for community engagement and outreach. A common approach to attracting new members was to engage the community through some sort of activity at the Makerspace, such as giving a tour, hosting a class, showing how the equipment in the Makerspace works, and then relying on word-of-mouth from those who attended a Making activity to recruit other interested community members to a future Making activity.

This description of using Making to attract new members differed from the descriptions of Making from engineering deans and engineering technology deans and department chairs, with a few exceptions. For engineering deans and engineering technology deans and department chairs, Making is used as a way to enhance classroom learning, engage engineering students through problem-based learning and providing engineering students with hands-on and self-directed opportunities to create things. Sometimes, problem-based learning activities included engagement with the local community through students creating products based on requirements that came from local community members, for example, industry partners providing input on requirements or feedback on design. Engineering deans and engineering technology deans and department chairs did not view Making as a way to attract new students to engineering who would not have entered engineering otherwise, with a few exceptions.

As reported by those who teach at the K-12 level and participated in the non-Engineering academic Maker community survey, K-12 Making initiatives could serve to attract and retain a diverse body of students in engineering and engineering technology. Making is a way to introduce engineering design principles to students who may later become interested in majoring in engineering or engineering technology as undergraduates.

Future Research

Based on our survey, we are unable to explain why schools with multiple Makerspaces more frequently incorporate Making into their curricula and reported more positive student outcomes attributed to Making. Our best guess is that schools where Making was initiated by faculty members and department chairs tended both to have Makerspaces at multiple locations and incorporate Making into their programs. At schools where Making was first championed by a university president, provost, or dean, the Makerspace might occupy a single central location and faculty members would be less likely to incorporate Making into their curricula. A study that looks at the history of the development of Making at various universities that have distributed Makerspaces versus those with one central Makerspace would help shed light on this unexplained finding and help guide other engineering and engineering technology schools in the development of Makerspaces on campus.

Another area for future research is documenting how schools can engage K-12 students in Making activities so they become familiar with Making and interested in engineering and engineering technology. We are aware of engineering schools using Making to engage K-12 students, but these examples were not reported in our survey. Documenting and describing ways in which K-12 students can be engaged though Making could help engineering schools develop outreach and engagement approaches to engage and attract a more diverse group of students to engineering and engineering technology.

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