Citizen Science Maker Summit

Arizona State University

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School for the Future of Innovation in Society
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Citizen Science Maker Summit

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Learning Outcomes and Next Steps

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Abstract

Arizona State University and SciStarter hosted the "Citizen Science Maker Summit" at the ASU Chandler Innovation Center in Chandler, Arizona. The day-and-a-half event brought together academics, practitioners, educators, citizen scientists and makers to catalyze and strengthen collaborations between the communities. Objectives included the following: Develop a framework for a public-facing database of common citizen science tools to complement SciStarter's database of citizen science projects and events; Identify real-world case studies including efforts to identify, build or improve low-cost tools for citizen science; Address issues of access: how to better reach and support underrepresented communities and educators around citizen science and Making; and, explore plans for future citizen science and Making collaborations. This paper synthesizes some of the above objectives into four learning outcomes identified during the summit: (1) Successful citizen science and Maker projects require participation from a variety of stakeholders; (2) People (participants and project leaders) want information about, and access to appropriate and reliable tools to effectively engage in citizen science; (3) Tools designed by or modified by Makers can be used in citizen science projects; (4) Tool and project design are vital for data quality and participant understanding. Following each learning outcome is research illustrating how SciStarter's Tools Database could addresses some of the needs identified during the Summit.

Arizona State University

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Introduction

"There's a large community of people interested in citizen science and making." – Micah Lande, Ph.D., Assistant Professor, Ira A. Fulton Schools of Engineering at Arizona State University

Citizen science encompasses a diverse range of activities, such as birdwatching, weather monitoring, processing and analyzing astronomical data, and do-it-yourself science projects (Pew 2017[1]).[2] The Maker movement is an umbrella term for independent inventors, designers and tinkerers; a convergence of computer hackers and traditional artisans (AdWeek 2014[3]).

Sometimes referred to as DIY-ers or "Citizen Engineers," individuals from diverse backgrounds – art, science, fabrication, manufacturing – produce, build and compose innovative objects.[4]

Overall, 16%, or one in six, of U.S. adults report having participated in citizen science or Maker activities (Pew 2017[5]).

What unites these two fields is the involvement of the public in projects and endeavors typically reserved for credentialed professionals and their organizations.

Both movements have attracted the attention of academic researchers, practitioners, journalists, funders, policymakers, and formal and informal educators, to varying degrees.

Boundary organizations -- museums, non-profits, civic spaces, etc. -- have engaged the public in citizen science and Maker activities. Organizations that facilitate access may be part of an academic institution, museum, church, for-profit, etc. Academics debate the differences between Makerspaces, Hackerspaces and Fab Labs, which all utilize DIY techniques, but characterize them as *"a community workshop[s] where members share access to tools in order to produce physical goods."*

The National Science Foundation has funded related research and public programs. The White House has hosted public events to catalyze investment in and support for both movements. Communities of Practice have formed around both movements.

However, even with these similarities, too few attempts have been made to leverage and unite these communities to maximize collective impact.

A growing body of literature suggests now is the time to bring the creativity, talents, and best practices of the Maker movement to bear on a particular issue weighing on the field of citizen science: the development of, and access to, low-cost instruments. For example, lack of access to, and understanding of, required technology contributes to the extremely high (80-95%) attrition rates for citizen science projects.[6] The Citizen Science Maker Summit ignited key discussions on this topic which are summarized in the pages to follow.

SciStarter[7] (the largest source of citizen science projects and a research platform used by ASU and other universities) and ASU's SFIS (with expertise in use-inspired, participatory research on citizen science and MakerEd) consider the convergence of these two movements as a potentially powerful way to further disrupt the status quo. The Citizen Science Maker Summit was inspired by a collective desire to 1) augment who participates in the scientific process, 2) accelerate participants' access to information, opportunities, tools, and resources , and 3) introduce Makers and manufacturers of low-cost tools to citizen scientists and project organizers who many be in need of existing or future tools and/or introduce citizen scientists and project owners to Makers who may be able to create new tools to fuel citizen science data collection or data analysis.

“There’s a large community of people interested in citizen science and making.”

—Micah Lande, Ph.D., Assistant Professor, Ira A. Fulton Schools of Engineering at Arizona State University

Overview of Summit

The one-and-a-half day Summit included participants from K-12 schools, universities, museums, libraries, foundations, the private sector, federal and state government, tribal government, nonprofits, and members of the public. It was held at the ASU Chandler Innovation Center. On the first day, the morning was comprised of keynote speakers and lightning talks and the afternoon was a series of breakout sessions followed by a un-conference session.[8] The interactive breakout session themes were: Maker-to-Manufacturing, Making Tools Discoverable, and Data Quality. The second day featured a closing keynote address followed by community commitments to collaborate.

The following learning outcomes and recommendations for next steps are based on media reports about the Summit, participant feedback, and related independent research developments following the Summit.

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Learning Outcomes

To open the conference, David Lang, Founder of Open ROV, a community forum dedicated to building and distributing drones for underwater exploration, introduced a visual aid to talk about the Maker and citizen science movements. The graph below, known as Gartner's Five-Step Hype Cycle, is used to describe public reactions to new technological innovations and movements and it can be applied to the citizen science and Maker movements. Lang said he believes the citizen science movement sits close to the beginning, just after the "Technology Trigger," while the Maker movement is further along, near the beginning of the "Slope of Enlightenment," indicating that the citizen science movement is rather nascent while the Maker movement has had time to evolve and establish some structure in defining what the field is and what it is not.

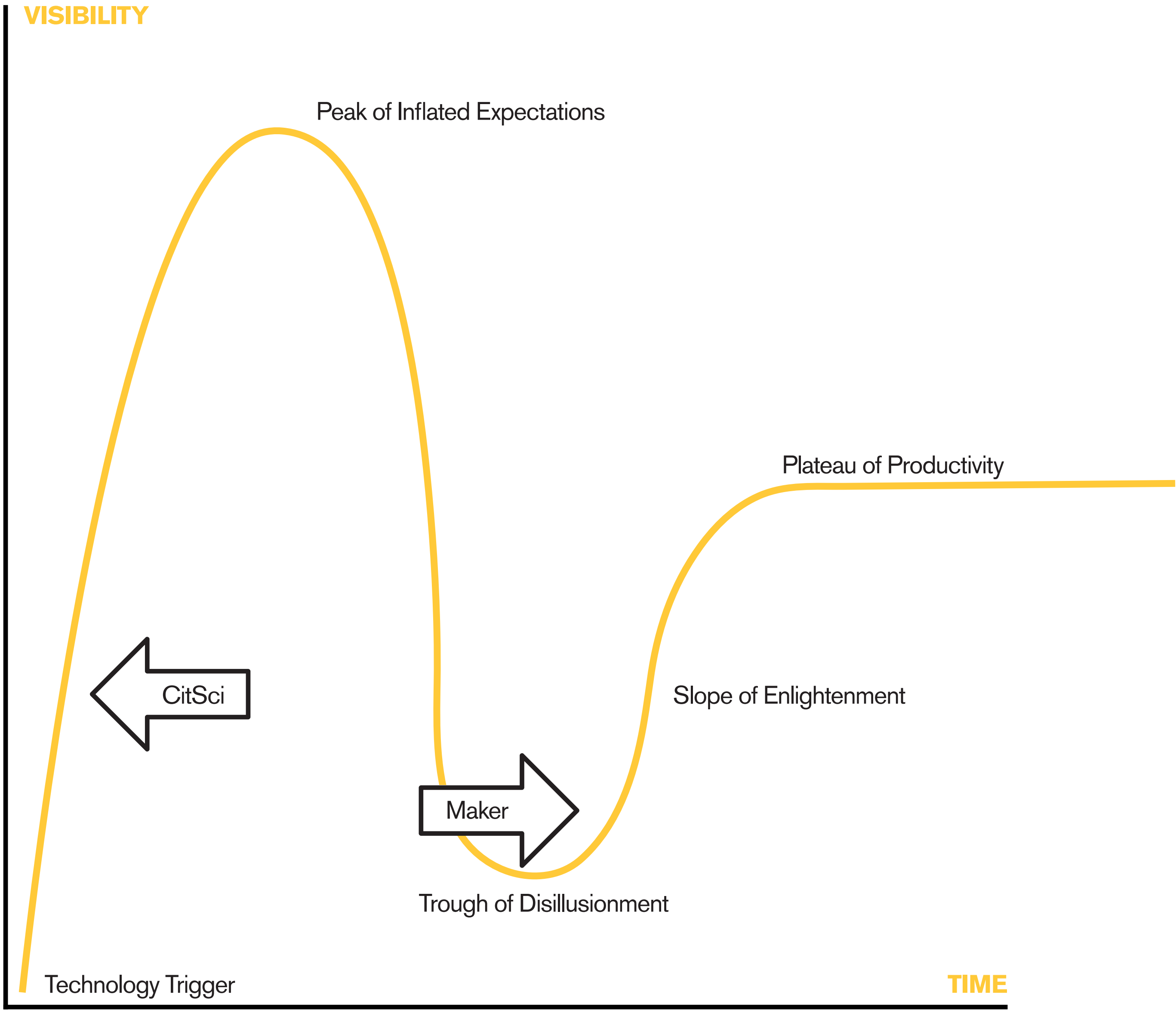

Figure 1 Citizen Science (CitSci) and Maker Movements plotted on Gartner's Five-Step Hype Cycle. Source: Gartner.com.

Learning Outcomes

1. Successful citizen science and Maker projects require participation from a variety of stakeholders.

"The scientific curiosity of a whole host of people who have not normally associated themselves with the scientific process has been liberated to the point where they can set their own agendas, create their own tools and techniques, and not have to rely on the good graces of established scientists and engineers." - Dave Guston, professor and founding director of the School for the Future of Innovation in Society at ASU, where he is also co-director of the Consortium for Science, Policy and Outcomes.

Summit participants expressed that in order to achieve the true potential of a co-created or community citizen science research project (defined as community involvement in all of the following: question generation, project design, data collection, synthesis and publication and/or policy action resulting from the project) *all* stakeholders should be invested and involved on some level.[9] Sophia B. Liu, Innovation Specialist with the U.S. Geological Survey, noted that the majority of citizen science projects are contributory, in that volunteers supply data to a scientist-led project where the professional scientist defines the research question and agenda, leaving little room for more meaningful contributions from a citizen scientist or Maker.[10] So, while Guston's claim is accurate -- in that the scientific process is now open to wider public participation -- there are still some unknowns about who exactly is participating in these projects and spaces and how deeply they are participating.

Take, for example, this insight from Dr. Raj Pandya[11]: "Citizen science is a powerful tool for connecting people to science, but in the US, such initiatives have not connected as well to groups that have been historically underrepresented in science. Research suggests that while several factors contribute to this lack of diverse participation in citizen science, the critical hurdle may be an absence of alignment between community priorities and research objectives." Like many volunteer-driven movements, participants' time is a key factor. Non-affluent communities tend to lack access to free-time, resources and other support structures needed to participate in these projects.[12]

Photo Credit: Lea Shanley

Trey Lathe, former director of MakerEd, cautioned that if not intentionally designed to attract, support, and benefit diverse communities, the Maker and citizen science movements may miss opportunities to move the needle.[13] Therefore programs like Maker VISTA, which places a Maker educator into "high-need communities," were discussed as model to consider in an effort to provide more equitable access to these movements.[14]

It's important to engage decision-makers in the design of projects and tools, but there's no guarantee this will result in policy-related action.

There may be a gap in moving information-to-action if key decision-makers (regulators, policymakers, elected officials, etc.) are not involved in the early stages of the project and/or tool design and if data collected and shared appear to be random and not "orderly." Nancy Stoner, from the Pisces Foundation, illustrated the importance of such collaborations and design considerations[15] through a real-world example in Virginia. (Others have also advocated for deeper collaborations between community citizen science groups and regulatory agencies in order to bring about action and change.[16])

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Photo Credit: Lea Shanley

Each summer, in Virginia's Shenandoah River Valley, residents face a nutrient pollution issue in their river: algae blooms. An active, local chapter of the national initiative, Riverkeepers, started documenting these algae blooms through photographs and submitted their findings to the Virginia Department of Environmental Quality (VADEQ), the regulatory agency charged with setting environmental standards to protect state residents. The VADEQ initially rejected the Riverkeepers' data because of a lack of documentation about the protocols and standards used to collect and interpret these data (e.g. time, location, size, etc.). Armed with these insights, the next summer, the Riverkeepers were able to modify and document their protocols and data to align with the requirements of the VADEQ. Although this was cited as a promising example of how a well-designed project can achieve greater impact, the authors' research turned up a disappointing footnote. In May 2017, the Potomac Riverkeepers Network filed a lawsuit challenging EPA's approval of Virginia's decision to not list the Shenandoah as 'impaired,' despite excessive algae blooms and nutrient pollution.[17]

Stoner also shared outcomes of a Pisces Foundation/Intel national survey.[18] This can be found in the following section.

2. People (participants and project leaders) want information about and access to appropriate and reliable tools.

In 2016, the Pisces Foundation, with support from Intel, surveyed "watershed organizations, schools and citizen volunteers to determine how they use monitoring equipment and information technologies to collect and disseminate water quality information. In addition the survey gauged their interest and awareness of emerging water quality technologies that could bring down the cost or improve the quality of the information that they collect.[18]" The major findings are summarized below.

84% of respondents believe "widespread availability of low-cost equipment could affect major improvements in water quality."

- The top 4 needs for <u>low-cost monitoring equipment</u> are to: target problem areas; use as a screening tool for advanced/expert level monitoring/investigation; report pollution incidents; use as part of monitoring and verification protocols for watershed protection and restoration projects, etc.
- The top 5 <u>desired parameters</u> to monitor using low-cost equipment: nutrients (forms of nitrogen and phosphorus and associated chlorophyll A concentrations; bacteria (fecal coliform, E.coli, etc.)); dissolved oxygen;

electrical conductivity and turbidity. Quite a few survey respondents also monitor for macroinvertebrates to measure the health of the biological community in water bodies.

- Survey respondents were particularly interested in monitoring equipment that costs less than $100 per monitoring device.
- Most survey respondents currently use manual methods for gathering data (i.e., field kits or grab samples with lab analysis) but many would prefer to use automatic or semi-automatic means of data collection.
- The top 4 desired features of low cost monitoring equipment are durability, in field data entry, remote sensing and data loggers, and metadata capture.

These findings provide an early-stage roadmap for Makers and low-cost manufacturers to address an explicit need articulated by the citizen science community. They also complement research conducted by SciStarter and ASU.

Photo Credit: Marissa Huth

Making Tools Discoverable: Identifying Barriers to Participation

SciStarter is an online database featuring a wide variety of over 1600 citizen science projects and events taking place all around the world. A visitor to the website can search for projects and events using filters including location, interests, dates, etc. In 2016, SciStarter and ASU were awarded a National Science Foundation Innovation Corps for Learning (iCorps-L)[19] grant which prompted the teams to conduct in-person, phone, and Skype interviews with 110 people about their experiences with citizen science. Interviews frequently surfaced a common "pain point" among citizen science volunteers and project owners: confusion about technologies and instruments used to facilitate data collection or analysis.[20] Without an understanding of and access to appropriate tools, people struggle to fully participate in citizen science projects. In a movement centered around engagement, this is a sizable obstacle.[21]

"The fact that the National Science Foundation has seen the Maker-to-Manufacturer and the Citizen Science [movements] come together indicates that something is happening and we have to pay attention to it." - Ariela Zycherman, AAAS Fellow at the National Science Foundation.

On the SciStarter project database, 249 of 864 sampled citizen science projects require some type of tool. A tool being defined as an item that can be used for measuring, observing, sensing, recording or otherwise collecting information about a variable(s) within a project.

Sometimes the tool is standardized to allow for comparable measurements between different study sites or citizen scientists. For example, the citizen science project CoCoRaHS measures and maps precipitation through a customized rain gauge. Other times, the project does not rely on a specific brand

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—Ariela Zycherman, AAAS Fellow at the National Science Foundation

or model, as long as the general function can be performed.

The goals and outcomes of Maker projects vary, but collaborative design is common as is the use of open source hardware and code. David Lang (Open ROV) noted his reliance on Makerspaces in order to access tools and the online Maker community for trouble-shooting technical questions.[22] While Lang had time and resources to find and use these physical and online communities, other summit participants expressed concern that these spaces were not well known enough.

Another noted barrier to tool and tool-making access raised during the Maker to manufacturing panel was the cost of components. The Pisces Foundation and the Intel Corporation's survey[23] found that of the 130 respondents to this survey the third leading barrier to carrying out low-cost water quality citizen science projects is equipment, behind funding and staff resources. In addition, the parameters that are most important to monitor in water quality projects, nitrogen and phosphorus, have the least low-cost technologies available. This is what drove Nancy Stoner of the Pisces Foundation to ask the crowd of Makers at the summit to create these low-cost nutrient sensors.

While MakerEd is hopeful in increasing access through expanding pedagogy and resources for creating Makerspaces in schools, SciStarter is working on increasing communication about existing spaces and connecting people to the right tools to accomplish the projects. One experiment is through lending tools via libraries. SciStarter partnered with NASA's GLOBE El Nino Project and developed a toolkit with all of the equipment participants needed to help NASA ground-truth satellite data (infrared thermometers, digital scales, etc). The kits were loaned through public libraries.[24] More recently, SciStarter and ASU, with support from the Institute of Museum and Library Services, are partnering with public libraries in AZ to support Libraries as Community Hubs for Citizen Science.[25] The project will provide citizen science toolkits for patrons to do citizen science at the library or at home.[26]

Making Tools Discoverable: Demand

After the British Petroleum (BP) Oil Spill in the Gulf of Mexico in 2010, Public Lab, then called Grassroots Mapping, began building DIY community satellites -- aerial balloon and kite mapping kits -- and lending them to communities for use mapping the extent and spread of oil on their coastlines.[27] This led Public Lab to introduce the idea of Lending Libraries as a way for communities to "check-out" tools from various informal locations to investigate environmental concerns. Since the BP oil spill, local groups of Public Labbers have coordinated the handoff of kits to each other in a completely distributed manner, using only a local mailing list, and without the support of a central tool repository. Despite being structured unlike a library, this decentralized system has worked well for years.

Based on the Public Labs model, SciStarter decided to quantify and qualify this need for tool access to assess whether their project website could serve as a facilitator of projects AND tools. SciStarter initiated a survey after the Maker Summit to gauge interest. Of the 100 surveys sent to citizen science project organizers whose projects require tool use, 47% replied. Of those who replied, about half manage national or global scale projects and half manage local projects.[28] Based on SciStarter project pages and interview responses, 33 projects appear to provide tools to their participants and 14 do not. About 50% of the projects that provide tools require training, supervision or both in order to use the equipment. Project owners choose to provide tools for the benefit of the volunteers and the quality of data. However, they report challenges in distribution, equipment maintenance and volunteer commitment. Some of the project managers who do not provide tools also cited distribution as a challenge.

When asked if they would like help from SciStarter selling or distributing tools for their project, 26% of project owners expressed interest due to increased access of their materials and help with distribution. A higher percentage of National or Global project managers were interested compared to local managers. Local disinterest typically stemmed from

Photo Credit: Lea Shanley

a desire to keep a local project small-scale and community-centric, a need for in-person training, or a need for regular staff supervision of the volunteers. Cost of materials for participants was also a concern as several project owners who expressed interest gave fee-related stipulations.

In addition to increased access and distribution help, project managers were excited about the potential lending libraries. However, they were concerned over potential maintenance and durability issues of the tools that may affect data quality.

Making Tools Discoverable: Defining the Fields

To match volunteers to existing tools, SciStarter began developing a tools database (https://scistarter.com/tools) to link citizen scientists to tools they can Build (DIY), Borrow (Lending Libraries) or Buy [Amazon, Inventables, etc]. More than 50 project owners participated in a tools survey in the summer of 2016 to evaluate how participants obtained the required tools for the project, tool cost, accuracy, complexity and more. These responses helped shape the emerging tools database by becoming the working draft of SciStarter's “Add a Tool” form, representing various requests for information ranging from the physical size of the item to instructions for use.

Sensor	Manufacturer	City/State	~Cost	Website
CanarIT	**Airbase**	Israel	$1,500	myairbase.com/#!tech-nology
CairClip PM2.5	**CairPol**	Mejannes les Ales, France	*	cairpol.com/index.php?lang=en
Speck	**Carnegie Mellon**	Pittsburgh, PA	$150	specksensor.org
DC1100	**Dylos**	Riverside, CA	$300	dylosproducts.com/ornod-cairgum.html
831	**Met One**	Grants Pass, ORa	$2,050	metone.com/particu-late-831.php
MicroPEM	**RTI**	Research Triangle Park, NC	$2000	rti.org/page.cfm/Aero-sol_Sensors
Eco PM	**Sensaris**	Crolles, France	*	v2.sensaris.com/store/index.php?route=product.product&product_id=66
PMS-SYS-1	**Shinyei**	Chuo-ku, Japan	$1000	shinyei.co.jp/STC/optical/main_pmmonitor_e.html

An example from the EPA's "Evaluation of Field-deployed Low Cost PM Sensors."

Citizen Scientist	Maker	Project Manager	Lender
Can I easily get this item?	Can I scale production to service participants?	Will participants understand how to use the tool?	Will people know how to use this (is this a turnkey tool/ project that requires little to no facilitation)?
Will I know how to use it?	Am I aware of, or can I make a better version or a new tool?	Has this tool been validated; will it produce accurate data?	Is this durable and free of many replaceable parts?
Am I confident it's the right tool for the project I joined?		Will this tool work in the location and environment where I need data collected?	Do I have the space to store it and capacity to promote it?

Figure 4 Tools Database user personas and common tool selection concerns.

SciStarter will model the EPA's approach to make key information about tools more discoverable. See Evaluation of Field-deployed Low Cost PM Sensors as well as the above illustration from the EPA.

Prior to the start of the ASU Citizen Science Maker Summit, the Wilson Center's Science and Technology Innovation Program, SciStarter and ASU hosted a workshop with twenty researchers, citizen scientists, Makers, and metadata experts. By analyzing the developing SciStarter Tools Database and a white paper examining 100 low cost citizen science technologies (commissioned by) the U.S. Environmental Protection Agency and authored by Margaret MacDonell/Argonne National Laboratory participants worked to refine which fields would be most important to database users.[29]

These potential fields developed during the workshop of the "Add a Tool" form were shared with more than 80 participants in the "Making Tools Discoverable" session at the Summit. The SciStarter Tools Database team asked Summit attendees to adopt one of the following personas while evaluating the proposed fields: Citizen Scientist, Citizen Scientist Project Manager, Lending Library, or Maker/Manufacturer while evaluating the proposed fields. While lending libraries may be concerned about the durability of an item or maintenance requirements, project managers want to know the specific function of the item to ensure that it's a good match for their project. Makers were more curious about the function, range and measurement capacity of the item. However, all groups were interested in learning how to obtain the item: Build, Borrow or Buy.

3. Tools designed or modified by Makers can be used in citizen science projects, and vice versa, but there are barriers

Several panelists at the conference illustrated that tools designed by Makers, or even citizen science project owners, were being used in citizen science or scientific projects. Katherine Ball, PhD student at the University of Washington's Ocean Technology Center,

Photo Credit: Lea Shanley

science project needs.[30] Previous sensors required too much training time so she wanted the instrument to be as easy as possible, building it with only 10 components. She optimized the tool for lay-knowledge use, increasing the chances that it would be used correctly.

David Lang, Open ROV, iterated on his underwater drone design until it was highly usable. He made the designs open-source and, today, a thriving DIY online community are sharing their own Open ROV-led investigations. OpenROVs are being purchased around the world, providing revenue to help sustain production. This is an example of an inherent tension addressed by open source supporters during the "Maker to Manufacturing" panel.[31]

Jeffery Warren, co-Founder and Research Director of Public Lab, approaches this tension through nurturing an open source community that creates and iterates on base "starter kits." Public Lab puts together the kits but places no patent on what is created from the kits. This allows for unrestricted creativity.

Another way to navigate this tension is the legal tool called Creative Commons licensure, specifically the share-alike clause.[32] The goal of Creative Commons is to provide legal tools for inventors that will allow them to retain some credit for their creations while sharing them for re-use free of cost. However, Rich Cameron, Co-Founder of Nonscriptum, noted that if an instrument is created with DIY-instructions, but uses a very expensive and patented part then it negates the point of open source in that it becomes prohibitive to make the instrument. The panel summarized that indeed there is crossover between the creations of Makers and citizen science projects, but there are questions that still remain which should be the subject of further debate and research such as:

- How to fundraise/price tools appropriately for citizen science projects?
- How to engage the interest of Makers in citizen science projects?
- How to match tools to appropriate projects?

Making Tools Discoverable: Finding the Tools

In an effort to make Maker and low-cost tools more discoverable to project organizers and participants, SciStarter released the alpha version of the Tools Database following the Summit. This alpha version was not publicized but contributors and reviewers were provided a URL to user-test the emerging fields developed during the workshop and Summit.
The majority of the 250 tool entries come from the material lists of existing SciStarter citizen science projects or from Makers. Recognizing the potential for Maker-made tools to aid in citizen science, open source platforms such as hackaday and instructables were searched to find tools that may match common citizen science objectives. Using the website's messaging feature, 60 Makers were invited to add their projects to the SciStarter tools database, and 25% added tools.

There are also several lending institutions represented in the database. However, early feedback revealed that some lending organizations (in particular MakerSpaces and BioLabs) required onsite or staff-supervised use of tools, requirements that were not part of the existing "Add a Tool" form. The database was revised based on this feedback. Now, when users search for a tool that "can be borrowed," they can see whether the tool can be "delivered," "picked up from a location," or "used on-site only." A text box allows for additional instruction as necessary.

Making Tools Discoverable: Matching the Tools to a Project

The 250 tools in the database represent a wide variation of make and models suitable for the various needs of individual citizen science projects. Each specific entry can be categorized into a general tool type for easy searching and comparison. For example, the entries for Air Visual Node, AirBeam, and Diffusion Tubes all vary in design, but are of the category "air quality monitors." The categories continue to be refined as more entries are added into the database and these early groupings have been helpful in understanding potential database organization. More work is needed to generalize these categories further into easy terms to search, but also to define what characteristics


Photo Credit: Lea Shanley


Photo Credit: Lea Shanley

define the emerging and flexible taxonomy. As of May 2017, 27 tool categories in the database can be used for five or more different citizen science projects. Binoculars, GPS, Magnification Tool, Measuring Tape and pH sensors can be used in ten or more different SciStarter citizen science projects. However, not all makes and models within these categories will work for every project, therefore project design, parameters for acceptable use of tools and sensors and clear documentation are critical elements to a successful project.

A supplemental taxonomy is illustrated in “Citizen Science Technologies and Opportunities,” commissioned by the EPA and written by Margaret MacDonnell et al at Argonne National Laboratories (unpublished). The 100 tools the authors identified in their literature review were divided into both topical categories of interest to EPA scientists (eg. microbial, water, air, elevation) and observation and measurement categories (eg. air quality, water quality, particulate matter, and relative humidity). The SciStarter Tools Database will likely apply tags to these topical, observation, and measurement categories to make it easier to search for and find the right tool.

4. Tool and project design are vital to data quality and participant involvement.

“I talk and write about data quality a lot because it’s one of the primary barriers to acceptance and support from the professional science community and that legitimization is part of what gets the work taken seriously.” - Andrea Wiggins, University of Maryland

Data quality is a large topic of discussion in the citizen science field. Inherently built into traditional scientific endeavors is a voucher of trust, bestowed upon engineers and scientists by a higher education and regulatory licensure system. However, in a field where the amateur public is creating scientific research projects with real-world applications, a major concern is data quality. Lea Shanley, former Co-Chair of the Federal Community of Practice on Citizen Science and Crowdsourcing, remarked during the panel that when they were speaking to federal government practitioners on citizen science, the same concerns were reiterated by federal employees: believability, liability, privacy and data quality. Because of this, there are many concepts about data quality and project design that were discussed during the data quality panel that illustrate ways to address these concerns in the field of citizen science and tool design.[33]

Andrea Wiggins, researcher at University of Maryland, introduced the term Fitness for Use where the quality of data is determined by whether it fits its intended use. Re-usability of that data is dependent on the documentation of how, why, what, when and where the data was collected , also known as metadata. Jeff Warren from Public Labs noted that in tool design for citizen created projects the actual tool isn’t the most important thing, it’s the lifecycle of the device and the documentation of how it’s used that is vital to its success in real-world projects.

Sophia Liu discussed iCoast where USGS scientists asked volunteers to take images of the coast in an effort to determine where erosion was occurring. In this situation it was cost prohibitive to commission a

Photo Credit: Lea Shanley

helicopter and staff in an effort to survey the coast. Instead it was much simpler to ask hikers to snap a photo with a geotag in order to understand erosion. The quality or depth of data wasn't as important here when the goal was to assess large-scale analysis and overarching trends.

The general consensus of the panel was that human-centered design is a process that can ensure tools and projects are designed for an appropriate level of data quality to match the objectives of a project. When designing a tool or a citizen science project, it's useful to imagine user-based scenarios from the perspective of the participant, rather than the scientist or project organizer.

For example, Ebird is a highly successful citizen science project where birders report their sightings online to a central database, which in turn provides information on migration trends, species occurrence and distribution to scientists. The team that built the platform asked the birders, the primary users, what they would most like to see in a platform like this.[34] Through asking them what they wanted, the Ebird team built a platform that would attract more volunteers and retain them – they went slow and asked the users detailed questions in order to improve data quality and user engagement.

One way to transfer information about acceptable data quality standards in policymaking and legal precedent is through challenges. In the fall of 2016, the U.S. Environmental Protection Agency conducted the Smart City Air Challenge inviting communities across the U.S. to envision a plan for deploying hundreds of air quality sensors to monitor local air quality and make that data public.[35] This allowed for dialogue between the users of the tools, the communities, and the potential users of the data, the EPA.

Making Tools Discoverable: Linking Tools and Projects

During the "Making Tools Discoverable" session of the ASU Citizen Science Maker Summit, more than 80 participants gave feedback about the emerging structure of the Tools Database. One common suggestion was the importance of being able to describe what the tool actually does and any limitations a user may encounter. Fields such as accuracy, precision, range and more were discussed as participants worked to find the balance between asking enough questions and still keeping the database general enough to apply to a wide variety of tools. The alpha database includes two text entry fields in which the tool can be described: "Brief description of what the tool should be used for" and "Range and/or other measurement specifications of this tool." A question on tool audience allows the user to explain any concerns for potential user error. The user entering the information will have to be descriptive and use precise vocabulary in order for a citizen science project manager to decide if the tool might be a good match for her project. Anyone can suggest a pairing between a tool and project, but the project manager will be the one to confirm whether the tool is fit for the intended use or not. The user review system (in development) will allow citizen scientists to comment on the ease of use, project managers to share their own reviews, and Makers to comment on tool design or other considerations.

In organizing and sharing key information about low cost instruments for citizen science, SciStarter hopes to: 1) advance research about the landscape of tools; 2) understand the potential for the tools' transferability across multiple projects, 3) help Makers identify gaps to fill; 4) create a more unified approach to democratizing science. We hope the emerging SciStarter Tools Database will help facilitate these interaction

"I talk and write about data quality a lot because it's one of the primary barriers to acceptance and support from the professional science community and that legitimization is part of what gets the work taken seriously."

—Andrea Wiggins, University of Maryland

Conclusions and Next Steps

Photo Credit: Lea Shanley

The ASU Citizen Science Maker Summit set out to explore the nuances and convergence of these movements and found that there are more similarities (participation of the non-credentialed public) than differences (motivations, support structures) between the movements.

Lastly, equal-access to projects, opportunities, resources, and tools was a recurring theme and one that deserves more attention.

Next Steps

1. Identify specific challenges and opportunities to address greater access:
    a. MakerEd VISTA places Maker-trained teachers in low-income communities to provide training on tools and how to use them.
    b. Public lab creates open-source tools to be reusable and facilitates a free online-forum for discussion.
    c. Global Open Science Hardware encourages and supports a growing and diverse, global community around the development of open tools: http://openhardware.science/about/
2. Expand access to and awareness of community Makerspaces, techshops, biolabs, tool lending libraries and other organizations that provide tools or DIY materials for little to no cost. Perhaps use these physical meet-up spaces as hubs to cross-pollinate citizen science and Maker communities.
    a. SciStarter Tools Database intends to allow community members to discover lending libraries in their neighborhood through the platform.
3. Broaden the roles and relationships of different types of stakeholders in the citizen science and Maker community (students, educators, government officials, academic researchers, manufacturers and industry leaders).
    a. Human-centered design exercises can inform project design to reflect the needs of a diverse set of stakeholders.
4. Increase communication between Makers and citizen science project owners during the design phase of the project.
    a. Makerspaces could host citizen science nights, inviting citizen science project managers to come talk to Makers about their needs.
5. Explore the role of citizen scientists as consumers of Maker-made tools.
    a. Public Lab and SciStarter are bundling assorted tools in kits that can be used for complementary projects.
    b. Private foundations should develop funding calls to explore the nuances of the Maker-citizen science interface. Foundations that align well with this nexus include:
        i. Infosys
        ii. Gordon & Betty Moore Foundation
        iii. Gates Foundation
        iv. Sloan Foundation
        v. Simons Foundation
        vi. Others (your ideas here!)

Making Tools Discoverable: Collaborative Tools Database

During the past year, SciStarter has explored how to organize research around the qualities and characteristics of instruments for citizen science with a goal of understanding what citizen science tools are currently available, how they are described by citizen science project owners and/or manufacturers, how they are (or could be) made discoverable and accessible by project owners and citizen scientists, what projects they can be used for, price ranges, durability, and more.

Much of this work was supported and accelerated through the triangulated nexus of three complementary initiatives and one related project currently under development:

- National Science Foundation EAGER grant to support the early development of a citizen science tools taxonomy; Award Abstract #1645382 (2016)
- National Science Foundation iCORPS incubation to apply a "lean start-up method" to test and validate the use of SciStarter as a broker between citizen scientists < > projects, projects< >instruments, and citizen scientists< > instruments; Award Abstract #1644554 (2016)
- SciStarter and Arizona State University's Citizen Science Maker Summit at ASU which brought together multiple communities to identify opportunities to improve the design of, access to, and use of low-cost instruments for citizen science. (2016)
- Institute of Museum of Library Services (IMLS) grant to support SciStarter and ASU's effort to create toolkits to support Public Libraries as Community Hubs for Citizen Science. LG-95-17-0158-17 (2017-2019)

Another outcome of this work is that the database can serve as a guide to help Makers, developers, manufacturers, researchers, and funders understand the current landscape of citizen science tools to avoid duplication and identify gaps. The current version of

Photo Credit: Marissa Huth

this database will not only make it easier for people to discover and access the tools, but it will identify where gaps exist and inform future possible tools, tool development plans, and how to scale up adoption and use.
SciStarter will include incremental features that complement the SciStarter project database including: 1) the ability to add "ratings and reviews" of the tools; 2) an open system so people can add more tools to the database within a structured protocol, including low-cost tools being developed by "citizen engineers"; 3) linkages between the tools and the project databases; 4) the ability to access the tools via a Build, Borrow, or Buy feature; 5) a Consumer Reports-style 3rd-party validation of a representative sampling of environmental quality tools. Protocols for this critical component will be documented and shared so others can model and scale up the validation of low cost instruments for citizen science.

This collective system will help make it possible for people to more confidently add, discover, recommend and access the right tools for citizen science. As a follow-up project, we envision adding another matchmaking feature so project owners can post standardized requests for the types of tools they cannot find but need to fuel their citizen science efforts and so Makers/manufacturers and frugal engineers can respond to the requests. Their new tools would be entered into the Citizen Science Tools Database where they would be validated and reviewed in the manner described above. It's easy to imagine how these components will work well together within this ecosystem.

Endnotes

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Biographies and videos of participants and panelists can be found here: **Makersummit.asu.edu**.

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