Community Biology Lab in Practice: a Pasteur's Quadrant Perspective

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Abstract. Pasteur's Quadrant categorizes research into three quadrants based on two dimensions: pursuit of basic understanding and consideration of utility. The ultimate goal is to create synergy between science and technology for economic advancement. Academic researchers working on basic research fall into the Bohr quadrant; engineers fall into the Edison quadrant of applied research. The Pasteur quadrant, use-inspired basic research, is largely occupied by government agencies, meaning that large organizations and bureaucratic structures define our practical research priorities. Critically missing from research infrastructure is community and societal input into setting priorities. Community biology labs enable community members to perform research. Because they are unique as volunteer-run, community-based organizations, community labs may be valuable additions to the quadrant paradigm. We use autoethnographic study based on our own long-term participation, interviews with participants, and literature and website reviews to understand the nature of community lab projects and participants' motivations. We show that the Open Insulin, Real Vegan Cheese, and DIY Bioprinter projects each fall into Pasteur's quadrant. Community labs enhance work in this quadrant since they are enterprise organizations that integrate diverse expertise, pivot between basic and applied work quickly, collaborate easily, focus use consideration on local priorities, and prioritize accessibility and affordability.

Keywords. community biology lab, basic research, applied research, citizen science, Pasteur's quadrant, social innovation

Introduction

The term 'establishment science' refers to the science performed by large institutions such as academia (e.g. colleges and universities), governmental bodies (e.g. National Institutes of Health), and industry. This science is primarily funded by government grants and is far removed from the taxpayer that is funding the research. The funding is first obtained from the taxpayer and given to funding sources; the funding sources then grant funds to the established scientists in a loosely-defined merit-based manner. The science is then carried out far removed from the taxpayer. Eventually, the findings from this establishment science trickle back to the taxpayer, but there is nothing to guarantee that these findings will be impactful or relevant to those who funded the research. This method of funding and discovery in establishment science does not particularly encourage science that benefits the taxpayer directly. Additionally, increased competition for the limited pool of research funds leads to short-term thinking and dampens the creativity of researchers and their willingness to pursue risky projects [1]. As stated by Stu Cantrill, Chief editor of Nature Chemistry, "...the beginning of an assistant professorship will

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be the closest to true intellectual freedom that most scientists have in their career; perhaps the only time to imagine and pursue risky ideas with money untied to the requirements of funding agencies or companies" [2].

Historically, science has been defined by a harsh dichotomy: research is categorized as being either basic or applied. The goal of basic research is to answer previously unexplored questions with minimal focus on how the results of that research will directly impact society. In contrast, applied research aims to generate a product that makes the research useful to a consumer [3]. Donald Stokes aimed to redefine this harmful and false dichotomy after being inspired by the work of Louis Pasteur. Pasteur's initial aim was to solve an industrial problem, namely that beet juice was being used to produce alcohol, but occasionally this process produced unexpected sourness (lactic acid) rather than alcohol [4]. Although he started with an applied research question, through this work he discovered anaerobic microorganisms and anaerobic fermentation, a fundamental mechanism in cells. In his book *Pasteur's Quadrant*, Stokes uses this example to reimagine the classification of scientific research, using instead a two-dimensional scheme in which research could be categorized by the degree to which it pursues basic understanding and the consideration that it gives to the utility of the findings [5]. Stokes defined three of the four resulting quadrants as (1) basic research (high pursuit of basic understanding, low consideration of use), (2) applied research (low pursuit of basic understanding, high consideration of use), and (3) use-inspired basic research (high pursuit of basic understanding and high consideration of use) (see Figure 1). This third quadrant, Pasteur's Quadrant, highlights that research can be both applied and offer fundamental contributions to science as a whole.

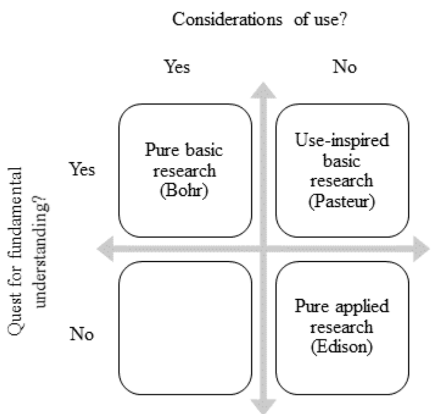

Figure 1 Stokes' two-dimensional continuum of research as defined and adapted from [5].

In Stokes' scheme, the quadrant of basic research is filled by establishment scientists. In contrast, the quadrant of applied research is filled by industrial scientists and engineers. But notably absent is a significant presence in the quadrant of use-inspired basic research; the primary example being government and military research. This quadrant is important because, as Stu Cantrill explains, "mission-oriented research inspired by the societal need both protects fundamental science and advances vital economic and social interests" [2]. The predominance of government and military researchers in this quadrant again runs the risk that the questions being prioritized will remain distinct from those of greatest interest and utility to the broader community. In this paper, we sought to examine whether community labs might be another form of organization that occupies this space, and whether they therefore make a valuable contribution to reimagining how we envision scientific research and its priorities.

Community biology laboratories are spaces that allow community members to take part in biological research and experimentation. These spaces operate independently from government funding and are therefore more intimately tied to the communities that they serve, especially since community members organize and direct these spaces. Community biology labs reverse the canonical relationship as the people have a direct, hands-on relationship to the science happening in their community.

Community biology labs are centered around three pillars: social ambition, affordability, and accessibility. Social ambition results from the direct involvement of the community performing the research. The needs and values of the community will be reflected directly by the science being performed as an artifact of their involvement. Community biology labs aim to be affordable for participants as well as for recipients of the end users of the research as their goal is to minimize costs [6]. The biology performed and generated is more accessible for both participants and recipients as they operate under the practice of open science which prioritizes transparency, data sharing, and accessibility [7]. Because community biology labs are not reliant on external sources of funding, they also benefit from increased flexibility in the projects they can pursue and the risks that they can take.

In this article, the authors performed a survey of current literature as well as surveying the experiences of participants and leaders in nine diverse community science labs to better understand where these organizations fall within the 2-dimensional classification continuum described by Stokes. We find that community biology labs are positioned as key assets for communities across the U.S, that the social ambitions that drive community science offer flexibility to answer the questions and needs that are most important to the community, and that these bottom-up initiatives better tailor solutions to the local context. Taken together these findings affirm the position of community biology labs in the use-inspired basic research (Pasteur's) quadrant of Stokes' 2-dimensional classification paradigm.

1. Methods

1.1. Survey and Interview Methods

We used two semi-structured focus groups of 30 high school students and 3 science educators to pilot our survey and incorporated their feedback into our final survey instrument. The survey consisted of 22 questions and featured a combination of multiple-selection questions to gather information about participants' community lab participation and their demographic information as well as questions about the participants' degree of participation in particular activities which were scored on a 5-point Likert scale; many questions also had the option for open-ended responses if the categories provided did not encompass the participant's experiences.

We selected 9 community labs across the United States to survey: Genspace, NYC, Baltimore Underground Science Space (BUGSS), Baltimore MD, CounterCulture Labs, Oakland CA, BioCurious, Sunnyvale CA, Biotech without Borders, NYC, BioBlaze Community Bio Lab, West Chicago IL, SoundBio, Seattle WA, Xinampa, Salinas CA, OpenBioLabs, Charlottesville VA, and BosLab, Boston MA. The survey was administered through Qualtrics software and was open for two and a half weeks. 73 community lab participants responded to our survey. Survey responses were converted from text to numerical values using Excel and analyzed using a SPSS statistical package to generate descriptive statistics.

In addition to our quantitative survey, we also conducted interviews with leaders from 6 of the 9 community labs; each was an Executive Director, Founder, or Board member. These interview transcripts were coded and assessed using deductive and inductive approaches [8] by two independent coders and resolved to achieve agreement by one of the two.

2. Results

2.1. Quantitative understanding of participant's engagement with community labs

To understand where community labs might fit into the Pasteur's quadrant paradigm, we first wanted to understand what motivations bring people to community labs and what their intentions are for their participation. We therefore surveyed 73 participants at 9 community labs across the United States to determine the range of ways and reasons that people became involved from this varied population. Overall, participants had a median age of 32 (range from 13-79); 49% were female, 48% were male, and 3% did not identify their gender; 27.4% were Asian, 9.6% were Black, 5.5% were biracial, 6.8% were Latinx, 45.2% were White, and 5.5% did not identify their race.

We first asked how participants heard about the community lab that they attend the most often (Table 1). Respondents indicated a wide range of entries into the lab community, with many becoming involved through the social connections of a friend, family member, teacher, coworker, or other community lab participant (86.30% total) and others discovering the lab through lab communication through social media, websites, or a newsletter (54.79% total). These data indicate that participants found their way to community labs through diverse routes with a significant percentage perhaps specifically seeking out a research space through a web search.

Table 1. Mechanism by which participants discovered the community lab that they attend the most often. Participants could select as many options as were applicable.

Mechanism	Percent of respondents
Friend(s)	31.51%
Family	10.96
Teacher	6.85
Someone at work	13.70
A community lab member	23.29
Social media	17.81
Website	32.88
Newsletter	4.11
Other	17.81

Once we understood how participants found their way to a community lab, we wanted to understand what their motivations and goals were for their involvement and why they became involved (Table 2). Community labs are distinct from other science spaces because they serve dual roles as both education and research spaces. Consistent with this, we found that a significant number of participants attended the lab with their primary goal being education (84.93% attend because of their personal interest in science or to improve [their] skills and knowledge for personal development, and 45.21% attend simply to explore). 64.38% of participants indicated that they engaged in as part of their community lab involvement. Of all participants, 34.25% expressed their primary motivation being to work on a project for a special cause and 9.59% had the motivation of making money (Table 2). Of those who selected "Other" as their response, two indicated that their motivation was to advance their company's research and development goals or to advance research for a specific project. These results are consistent with the responses to other questions for which 64.38% collaborated with others to solve a problem, 52.05% solved a problem when carrying out a project, 39.73% designed something of people other than themselves, and 32.88% made something personally meaningful to them (data not shown). While the vast majority of members had an educational motivation for becoming involved with a community lab, a significant number therefore also had distinct goals of solving problems, creating solutions, and making something meaningful to themself or to others.

Table 2. Motivations for joining a community lab and what participants hoped to gain from their involvement. Participants could select as many options as were applicable.

Mechanism	Percent of respondents
I go to work on a project for class	10.96%
I go to work on a project with a goal of making money	9.59
I go to work on a project for a special cause	34.25
I go to meet new people with similar interests	71.23
I go to hang out with colleagues, friends, or family	34.25
I go because of my personal interest in science	84.93
I go to improve my skills and knowledge for personal development	84.93
I go, but without a plan to achieve a particular goal (e.g., to explore)	45.21
Something else	13.70

Although most community lab participants do not have advanced scientific training, we were surprised by the degree and variety of ways in which they self-identified as scientists (71.23%), engineers (34.25%), innovators (31.51%), and technologists (24.66%) (Table 3). A significant number of those engaging in community labs therefore have a positive self-conception of their ability to engage in the scientific process, problem-solving, and creation of new systems and understandings rather than as novices who simply attend the community space to passively learn from those more experienced.

Table 3. Self-identification of community lab participants. Respondents could select as many options as were applicable.

Identification	Percent of respondents
Learner	80.82%
Maker	38.36
Artist	24.66
Engineer	34.25
Scientist	71.23
Designer	21.92
Software developer	9.59
Innovator	31.51
Biologist	54.79
Technologist	24.66
Entrepreneur	16.44
Inventor	10.96
Tinkerer	30.14
Hobbyist	34.25
Other	12.33

2.2. Participant's engagement with community labs as interpreted by lab leaders

In surveying lab leaders, our goals were to understand the mission and structure(s) of community labs, the activities that go on there, and the nature of participants' interactions. All five of the community lab leaders expressed their organization's mission as being one of making the tools of science more accessible for those who want to engage in science practices outside of traditional establishment science spaces (that "science didn't belong behind closed doors and in the ivory tower"). The leaders spoke of the mission being one of providing "shared physical space, shared equipment, so that people could do their own science", "shared access to tools" "a space that's affordable, where innovation can happen and not just for the startups, but really [for] casual people who just want to get involved with biology". Leaders also made clear that the intent of making space and tools available is "so that people could do their own science" and frequently referenced the maker, hacker, and DIY movements; one lab leader remarked, "People come to us and they want to do a thing and we're like, "here's your platform."

Each community lab leader easily defined projects occurring in their spaces that were use-based. These projects were also highly collaborative and multidisciplinary, and lab leaders pointed to teams of materials scientists, engineers, and teachers working together, "a spirit of openness [where] everybody shares and is excited about science more", "cross pollination of people just getting to meet each other", "peer-to-peer learning", and "informal learning where people come in with different areas of expertise".

Many of the research projects that the lab leaders described were initiated by non-scientists; therefore, education is a crucial additional pillar that enables research at community labs. The leaders spoke of participants who "want to have a project, but they have no skills and no idea how to start a project" or those who "have maybe an end goal in mind, but do not know what will be required to get there". Each lab had formal or informal mechanisms to help novice members such as "access to mentors and access to experts", "providing an opportunity for them to learn about what goes into developing a biotechnology product", helping with "lots of little questions and issues in the lab that need[s] somebody with a lot of training", and "unpacking the mythology of science and like, what it actually looks like in a very physical hands on experiential way".

One lab leader discussed the importance of these knowledge resources for making the projects feasible: "We'll find a lot of people who will come into the lab and they might have very like lofty ambitions to create some sort of new life form or to address a particular human disease. But they, they won't know how to even start going about working on that problem….But then there might be things that they might find really interesting, that would be totally feasible if there could be somebody who could provide some guidance."

2.3. Surveyed Projects at Community Labs

To gain insight into the projects being done in community biology labs, we surveyed literature and websites for three active community labs projects: Open Insulin, Real Vegan Cheese, and DIY Biprinter.

1. Open Insulin. The Open Insulin Foundation describes itself as a 'team of biohackers' with varying relationships with insulin and diabetes [9]. Historically, insulin has been an increasingly expensive treatment despite the fact that

individuals with diabetes are entirely reliant on these medications to sustain their lives. The Foundation notes that insulin prices have doubled between 2012 and 2016 [10]. Their goal is therefore to develop a ‘community-centered model for insulin production’ to return control of insulin production and pricing to the end users. The Foundation works to develop novel protocols to produce short-acting and long-acting insulin analogs and to decentralize the pharmaceutical supply chain [11]. Open Insulin is performing basic research with its development of novel protocols to produce insulin analogs using methods that avoid replicating patented procedures. This work occurs at two US community labs: Counter Culture Labs in Oakland CA and Baltimore Underground Science Space (BUGSS) in Baltimore MD. Yet the work was initiated with a clear end-goal in mind, namely affordable insulin for all who need it. This use-inspired research that is occurring at two community labs working in collaboration under an open-source model therefore fits into Pasteur’s quadrant of the 2-dimensional classification scheme. (see Figure 2).

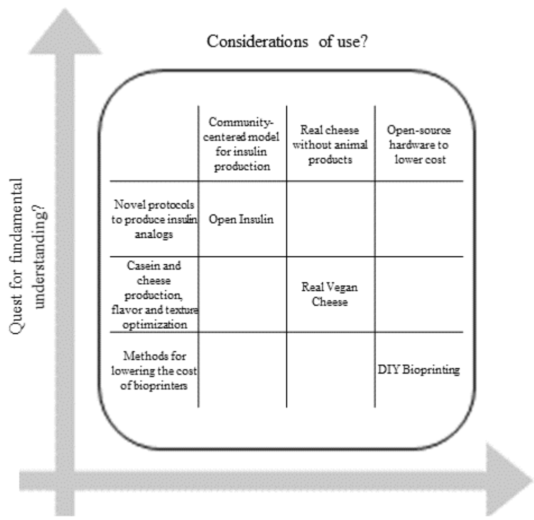

Figure 2. How three community lab projects fulfill the criteria of high consideration of use and high quest for fundamental understanding that define Pasteur’s quadrant.

2. Real Vegan Cheese**.** Real Vegan Cheese identifies itself as a grassroots non-profit research project with the goal of generating ‘real cheese’ without animal products [12]. Unlike companies that make vegan “cheese” from nuts, soy, or mushrooms, the project instead performs genetic engineering to produce milk proteins (casein) using cellular agriculture in yeast and other microbes. These milk proteins, which have been derived from cultured cells rather than animals, can then be fermented to generate ‘real’ cheese. Just as Open Insulin involves collaboration among community labs, Real Vegan Cheese is headquartered at Counter Culture Labs in Oakland CA and Biocurious in Sunnyvale CA. The basic science that occurs as part of this project ranges from studying how to produce casein protein, developing methods for making cheese from the recombinant casein, and troubleshooting methods to gain a ‘real’ cheese flavor and texture. In addition, the flexibility of

being free from responsibility to investors allows the project to expand in whimsical directions such as generating cheese from the casein protein encoded in the narwhal genome. Just as Pasteur's work began with the end-product (alcohol from fermentation) in mind, Real Vegan Cheese is focused on a usable end-product (vegan cheese identical to that produced from animals) yet is open to moving away from focusing solely on optimizing the product to following basic science questions that lead in interesting directions.

3. DIY Bioprinter projects. Since the development of the organ transplant technique, there has been a long line of individuals awaiting a life-saving organ donation, with 20 individuals dying in the US daily waiting for an organ [13]. Bioprinters represent a state-of-the-art tool for generating tissues and organs that could radically diminish the waiting list for organs and tissues [14]. Unfortunately, bioprinters are incredibly costly; DIY Bioprinter projects aim to cut the cost barrier to bioprinting [15,16]. In addition to their potential use for printing organs, DIY bioprinters have aided in the development of organ-on-a-chip models which can be used for drug testing against microbial diseases [14]. One example of this work being conducted in a community lab setting BioCurious' project of bioprinting with plants [17]. Traditionally, bioprinter testing requires stem cells, which is time consuming and costly. BioCurious BioPrinter project is making BioPrinting more cost effective by utilizing undifferentiated plant cells to test their machinery. BioCurious has also developed a method of incorporating cells into a matrix using sodium alginate. BioCurious performs this work with the goal of making bioprinting more accessible by lowering its cost and generating open-source hardware and methodologies. These projects performed basic research to develop proprietary methods for lowering the cost of bioprinters while generating products that are currently in use for important research and development. By working in this novel development and use-inspired area of research, DIY Bioprinter projects can be classified into Pasteur's Quadrant of the 2-dimension classification continuum.

Discussion

The two-dimensional classification continuum defined by Stokes disrupts the previously accepted scientific dichotomy between basic and applied research. Before Stokes' monumental work, basic and applied research were considered to be opposed, and one could not pursue basic scientific knowledge while also prioritizing the work's utility to society [18]. Though this conceptualization of research was ingrained in scientific culture, researchers actually engaged in combinations of basic and applied research, including Louis Pasteur and his development of the germ theory of disease as a paradigmatic example. Research in Pasteur's quadrant therefore embodies research that is dually motivated by discovery and invention: use-inspired research [5].

To place community biology labs, as new entrants to the scientific research community, within Stokes' 2-dimensional classification continuum, we surveyed participants of 9 geographically diverse community labs throughout the US as well as leaders of 5 of the 9 community labs. In addition, we examined relevant literature relating to three high-profile community lab research projects. We found that three characteristics of community labs place them squarely in Pasteur's quadrant: social ambition, a focus on accessibility, and flexibility.

Community lab participants are motivated by the social relevance of the work they are engaged with. They describe their motivation to join as being to 'meet new people with similar interests', a 'personal interest in science', and to 'improve new skills and knowledge (Table 2). These answers reflect a genuine interest in the research being performed, independent of broader career motivations, and the likely belief that it will benefit the greater good. This hope of connecting with individuals with similar interests reflects social ambition, or the idea of community members coming together around a shared goal. The three community lab projects that we explored in depth each had the end use as a primary motivator: providing affordable insulin, creating a more authentic vegan cheese product, and developing bioprinting technology for tissue engineering.

Participants' hope of building new skills and knowledge (Table 2) reflects the organizational goal of community labs to increase accessibility for individuals who might have been excluded from establishment scientific laboratory training due to the major hurdles of cost, time requirements, and racial bias. Survey participants were queried regarding their self-identification; 80% identified themselves as learners and 71% as scientists. While individuals could select both categories, the cohabitation between career and amateur scientists is notable and is a distinct feature of community lab spaces and research projects [6]. By engaging the community directly in research, the needs of the community are directly communicated to those performing the work.

Finally, the flexibility of community biology is a major factor in its success. Others have described how these spaces can quickly pivot between traditionally basic science discovery and application of discovery to address a need in the community [19]. In these spaces, there is an increased level of intellectual freedom and a wider range of collaborations due to their open and free recruiting process [20]. This nontraditional recruiting process is reflected in our survey where participants report discovering the laboratory through friends (32%), family (11%), other community lab members (23%), or online sources (51%) (Table 1). The flexibility is further reflected by lab participants describing that they 'go without a plan to achieve a particular goal' (Table 2), indicating a motivation to explore, an important piece of the scientific inquiry that can be lost in establishment science where clear end goals are important [21]. This flexibility can aid in evading the false dichotomy between basic and applied science and is likely to be critical for keeping scientific progress relevant to the needs of a fast-paced, modern society.

Concluding remarks

Establishment science has long been disconnected from the population that funds it. Community biology laboratories are a developing mechanism that can fill the gaps in establishment science and better serve communities through social ambition, accessibility, and flexibility. A key step in normalizing community labs is to define them within the context of other established research spaces. This piece aimed to define which quadrant community biology labs occupy on a two-dimensional classification continuum described by Stokes in his work *Pasteur's Quadrant* [5]. Given the primacy of the end-use of the research being conducted and its ability to attract new participants (Table 1), motivate participation (Table 2), and enable novices to self-identify as active participants and learners (Table 3) as well as the desire of participants to simply explore (Table 2) and the depth to which projects engage in basic research questions, we propose that community biology labs are centered within Pasteur's quadrant of use-inspired basic research. Future directions could further define and normalize community biology labs, address funding and regulation, follow career trajectories of those involved, and highlight the basic and applied findings of community science.

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