Transdisciplinarity and the Future of Engineering
B.R. Moser et al. (Eds.)

doi:10.3233/ATDE220644

Community Biology Labs in Practice: A Pasteur's Quadrant Perspective

Ibrahim ALDULIJAN[a,1], S. Nisa ASGARALI-HOFFMAN[b], Foad HAMIDI[c], Lydia STAMATO[c], Justice WALKER[d], Mo MANSOURI[a] and Lisa SCHEIFELE[e]
[a] *Stevens Institute of Technology, USA*
[b] *University of Maryland College Park, USA*
[c] *University of Maryland Baltimore County, USA*
[d] *The University of Texas at El Paso, USA*
[e] *Loyola University Maryland, USA*

Abstract. Donald Stokes developed a paradigm that categorizes research into three quadrants based on two dimensions: the pursuit of basic understanding and consideration of utility. His ultimate goal was to create synergy between science and technology for economic advancement. Academics working on basic research fall into the Bohr quadrant; engineers fall into Edison's quadrant of applied research. Pasteur's quadrant, use-inspired basic research, is largely occupied by government agencies and societal input into setting their research priorities is indirect. Community labs are organizations that enable community members to perform research. Yet their utility as scientific organizations is unclear; understanding where they fall within the quadrant paradigm may enable their role to be better defined and may help their contributions to the scientific endeavor to be more fully realized. We use interviews with participants, review of literature, and review of lab and project websites to understand the nature of community lab projects and participants' motivations. We show that the role of community labs falls most frequently into Pasteur's quadrant. Community labs' ability to integrate diverse expertise, pivot between basic and applied work quickly, support collaboration, and focus on local priorities makes them valuable additions to this quadrant and to the scientific research community.

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

Introduction

The modern paradigm, that research can be classified on a linear continuum from basic to applied, was codified by Vannevar Bush's 1945 report, *Science, the Endless Frontier* [1]. Bush, as the director of the Office of Scientific Research and Development, sought to create policies that would sustain the United States' scientific accomplishments made during the war years. He defined the goal of basic research as being to answer previously unexplored questions with minimal focus on how the results will directly impact society. In contrast, applied research aims to generate a product that makes the research useful to a consumer [2]. Importantly, Bush stated that "applied research invariably drives out pure" [1]; this aphorism established the idea that basic and applied research are antithetical and that when mixed, each degrades the value of the other.

[1] Corresponding Author, Mail: ialdulij@stevens.edu.

There have been notable critiques of this false dichotomy [3], one being by political scientist Donald Stokes in his 1997 seminal work *Pasteur's Quadrant: Basic Science and Technological Innovation* [4]. Stokes was inspired by the work of Louis Pasteur and Pasteur's initial aim of solving an industrial problem, namely to produce alcohol from beet juice without occasionally producing unexpected sourness (lactic acid) rather than alcohol [5]. Although he started with an applied research question, through this work he discovered anaerobic microorganisms and the fundamental mechanism of fermentation. Stokes uses this example to reimagine the classification of scientific research, using instead a two-dimensional scheme that categorizes research by the degree to which it pursues basic understanding and the consideration that it gives to the utility of the findings [4]. 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.

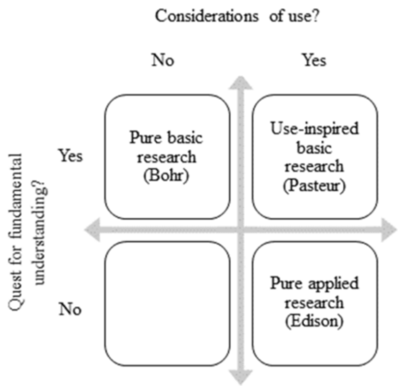

Figure 1 Stokes' two-dimensional continuum of scientific research as defined and adapted from [4].

Stokes recognized some limitations of his two-dimensional linear scheme [4]. For example, the matrix's boundaries are not intended to be rigid, and work in each quadrant can strengthen that in others: "the success of research directed towards social goals broadened the support for the pure research that would strengthen the capacity of the field as a whole to meet societal needs" (p. 103). He further acknowledges that the value of research questions will differ depending on who is making the appraisal and whether the judgment is being made before or after the research occurs. Because Stokes' goal in reconsidering the linear paradigm was to more effectively develop science policy, he uses that perspective to select the best solutions despite these limitations, arguing that the porous nature of the quadrants can be used to enhance basic research funding, that scientists can best judge both the scientific and social merit of their work, and that value should be appraised before projects commence.

In Stokes' scheme, the quadrant of basic research is filled by academic scientists such as those funded by the National Science Foundation. In contrast, the quadrant of applied research is filled by industrial scientists and by engineers, often funded by industry and government service agencies such as the Department of Defense. But notably absent is a diversity of fields occupying the quadrant of use-inspired basic research; the primary example being biomedical research funded by the National Institutes of Health. This quadrant is important because "mission-oriented research inspired by societal need both protects fundamental science and advances vital economic and social interests" [6].

Community biology laboratories are spaces that allow community members to take part in biological research and experimentation. These spaces often operate independently from government funding and are inextricably tied to the communities within which they are located. Community members organize and direct these spaces, so the needs and values of the community can be reflected directly in the science being performed. Many also operate wholly or partially under the framework of "open science" which prioritizes transparency and data sharing [7], making research practices and results more accessible to the public. Community labs enable a broader range of people to have a direct, hands-on relationship with science; they achieve this by prioritizing affordability for both participants and the end-users of the research by minimizing costs [8]. Because their funding sources may be diverse (membership and course fees, grants, donations, etc.) [9], community labs may have increased flexibility in the nature and riskiness of the projects they pursue.

Several community labs are now over a decade old, demonstrating their potential to make a long-term contribution to research infrastructure. However, their place and role among other established scientific enterprises remains unclear; this lack of understanding limits their ability to influence how we conduct scientific research and set priorities, and any benefits that could be realized from incorporating community labs into the scientific milieu remains unfulfilled. One way we can better understand their place in the scientific ecosystem is to define where they fall with respect to the pursuit of fundamental understanding and the consideration of use, i.e., in which quadrant of Stokes' paradigm. In this article, we surveyed the experiences of participants and leaders in 10 diverse community science labs and reviewed current literature, lab websites, and project documentation 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 valuable assets for communities across the U.S., that the social ambitions that drive community science offer flexibility to answer questions and address the needs most important to the community, and that these bottom-up initiatives tailor solutions to the local context. Taken together, these findings best situate 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-aged youth 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 10 community labs across the United States to survey: Genspace, Brooklyn, NY; Baltimore Underground Science Space, Baltimore, MD; Counter Culture Labs, Oakland, CA; BioCurious, Sunnyvale, CA; Biotech without Borders, New York City, NY; 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 an SPSS statistical package to generate descriptive statistics.

In addition to our quantitative survey, we also conducted interviews with leaders from 6 of the 10 community labs; each was an Executive Director, Founder, and/or Board member. Interview transcripts were coded and assessed using inductive approaches [10] by two independent coders and resolved by one of the two to achieve agreement. We present illustrative accounts from the interviews that reflect the most frequent themes that emerged in our analyses.

1.2. Literature, website, and project documentation reviews

To better understand projects that occur at community labs beyond our own experience as lab members, participants, and leaders, we reviewed all projects listed on the websites of the 10 community labs from which we drew survey participants. We selected three projects that had been actively running for multiple years, were well described both on websites and in peer-reviewed literature, and involved collaboration among multiple community labs. We reviewed websites, peer-reviewed literature, and participant descriptions from our interviews to understand and classify each project in Stokes' two-dimensional matrix.

2. Results

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

To understand where community labs might fit into Stokes' 2-dimensional classification scheme, we first wanted to understand how and why people engaged their local community lab. We analyzed survey data from 73 participants at 10 community labs across the United States lab to determine how and why people became involved. 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 entry points, with many becoming involved through the social connections of a friend, family member, teacher, coworker, or other community lab participant (86.3% total) and others through lab communication through social media, websites, or a newsletter (54.8% 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)	31.5%
Family	11.0
Teacher	6.9
Someone at work	13.7
A community lab member	23.3
Social media	17.8
Website	32.9
Newsletter	4.1
Other	17.8

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 serve dual roles as both education and research spaces; consistent with this, we found that the vast majority of participants attended the lab with their primary goal being education (84.9% attend because of their interest in science or to improve [their] skills and knowledge for personal development, and 45.2% attend simply to explore). Of all participants, 34.3% expressed their primary motivation being to work on a project for a special cause and 9.6% 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 64.4% collaborated with others to solve a problem, 52.1% solved a problem when carrying out a project, 39.7% designed something for people other than themselves, and 32.9% 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 also had distinct goals of solving problems and making something meaningful to themself or 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	11.0%
I go to work on a project with the goal of making money	9.6
I go to work on a project for a special cause	34.3
I go to meet new people with similar interests	71.2
I go to hang out with colleagues, friends, or family	34.3
I go because of my personal interest in science	84.9
I go to improve my skills and knowledge for personal development	84.9
I go, but without a plan to achieve a particular goal (e.g., to explore)	45.2
Something else	13.7

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 (71.2%), engineers (34.3%), innovators (31.5%), and technologists (24.7%) (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	80.8%
Maker	38.4
Artist	24.7
Engineer	34.3
Scientist	71.2
Designer	21.9
Software developer	9.6
Innovator	31.5
Biologist	54.8
Technologist	24.7
Entrepreneur	16.4
Inventor	11.0
Tinkerer	30.1
Hobbyist	34.3
Other	12.3

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

We further explored science engagement in community labs by surveying lab leaders. In interviewing lab leaders, our goals were to understand the missions and structures of community labs, the activities that go on there, and the nature of participants' interactions. All six of the community lab leaders interviewed 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," and "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 do-it-yourself (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 (see examples in Section 2.3). 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 some of 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. Projects at Community Labs

Lab leaders mentioned numerous projects being pursued at community labs. To build upon the information that they provided, we selected three projects that were the most well developed and for which the greatest number of sources (literature, websites, and project descriptions) were available. We used this additional information about three active community lab projects: Open Insulin, Real Vegan Cheese, and DIY bioprinter to assign these projects to a quadrant in the 2-dimensional Stokes continuum (Figure 2).

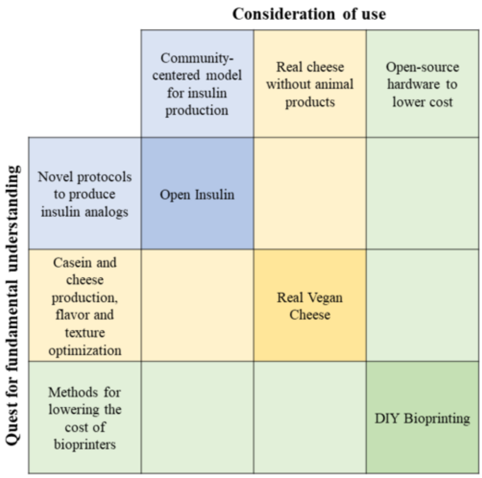

Figure 2. How three community lab projects fulfill the criteria of high consideration of use and a high quest for fundamental understanding that define Pasteur's quadrant.

1. Open Insulin. The Open Insulin Foundation describes itself as a 'team of biohackers' with varying relationships with insulin and diabetes [11]. Insulin has become an increasingly expensive treatment even though individuals with diabetes are entirely reliant on these medications to sustain their lives. The Foundation notes that insulin prices doubled between 2012 and 2016 [12]. Their goal is therefore to develop a 'community-centered model for insulin production' to give 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 [13]. Open Insulin is performing basic research with its development of novel protocols to produce

insulin analogs using methods that avoid replicating patented procedures. This lab 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, which 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 (Figure 2).

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 [14]. 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 [15]. 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 [14]. 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 engages in significant basic science experimentation to reach that goal.

3. DIY bioprinter projects. Since the development of the organ transplant technique, there has been a long line of individuals waiting for a life-saving organ donation, with 20 individuals dying in the US daily waiting for an organ [16]. Bioprinters represent a state-of-the-art tool for generating tissues and organs that could radically diminish the waiting list for organs and tissues. Unfortunately, bioprinters are incredibly costly; DIY bioprinter projects aim to cut the cost barrier to bioprinting [17,18]. 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 [19]. One example of this work being conducted in a community lab setting is BioCurious' project of bioprinting with plants [20]. Traditionally, bioprinter testing requires stem cells, and this process 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 [20]. BioCurious performs this work to make bioprinting more accessible by lowering its cost and generating open-source hardware and methodologies. These projects perform basic research to develop proprietary methods for lowering the cost of bioprinters while generating products that can be directly used for improving applications. 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 (Table 2).

3. 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 [1, 21]. Though the conceptualization of basic and applied research being opposed became ingrained, researchers such as Pasteur actually engaged in combinations of basic and applied research. By redefining the structure of the categorization paradigm, Stokes defined more complex ways of thinking about a project's contribution to basic knowledge and its utility; this included the definition of Pasteur's quadrant, representing research that is dually motivated by discovery and application: use-inspired research [4].

To place community biology labs, as relatively new entrants to the scientific research community, within one or more quadrants of Stokes' 2-dimensional classification continuum, we surveyed participants of 10 geographically diverse community labs throughout the US as well as leaders of 5 of the 10 community labs. In addition, we examined relevant websites, literature, and project descriptions relating to three high-profile community lab research projects. Taken together, we find that the research occurring at community labs fits most frequently, although not necessarily exclusively, into Pasteur's quadrant.

We found that community lab participants are motivated by the social relevance of their work. 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. Participants also expressed hope of connecting with individuals with similar interests and coming together around a shared goal (social ambition; Table 2). 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) could potentially indicate movement toward 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, and racial bias. Survey participants were queried regarding their self-identification; 80% identified themselves as learners and 71% as scientists (Table 3). 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 [8].

Finally, flexibility, or the ability to quickly pivot between discovery research and application of research findings to community needs, is important for the scientific enterprise [22] and is a major advantage of the structure of most community labs. In these spaces, there is a high level of intellectual freedom and a wide range of collaborations due to their open recruiting process [23]. 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). 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.

4. Concluding remarks

Stokes' goal in developing a new classification scheme was to enable collaboration between scientists and the government in the formulation of science policy [4]. Rather than having the quadrants segregate research projects, he envisioned a fluid interplay exemplified by the NIH model of funding work in three quadrants: Bohr's, Edison's, and Pasteur's. Community labs could fill gaps in the research ecosystem or could help move ideas between quadrants. A key step in integrating community labs is to define them relative to other established research spaces; in this case, by using the quadrant paradigm. Given the primacy of the research's end-use 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 depth to which projects pursue basic research questions, we propose that community labs are centered within Pasteur's quadrant of use-inspired basic research. We found three common characteristics of the labs: social ambition, accessibility, and flexibility; these characteristics enable the labs to work meaningfully within Pasteur's quadrant.

Future directions of this work could be to further define community biology labs and projects, examine their formal and informal interactions with other science organizations, understand their legitimacy within the scientific community and barriers to full participation, and highlight the basic and applied findings of community science. In addition, we note that many lab participants described that they 'go without a plan to achieve a particular goal' (Table 2). Stokes did not pay strong attention to the fourth quadrant (the one concerned neither with use nor with basic understanding) but indicated that it corresponded to skill-building or individual curiosity about particular phenomena, and he used the work of naturalists as an example. Community lab members' motivation to explore reflects an important piece of inquiry that can be lost in establishment science where clear end goals are important [24]; indeed, as Stokes notes, Darwin's theories emerged from his work as a naturalist. This fourth quadrant, and community labs' contributions to it, are certainly also worth deeper exploration.

References

[1] V. Bush, *Science, the endless frontier: a report to the President*, 75th Anniversary Edition, National Science Foundation, Washington, DC, 2020.
[2] P.J. Bentley, M. Gulbrandsen and S. Kyvik, The relationship between basic and applied research in universities, *High Educ,* Vol. 70, 2015, pp. 689–709.
[3] M. Gibbons, C. Limoges, H. Nowotny, S. Schwartzman, P. Scott, and M. Trow, *The New Production of Knowledge: the Dynamics of Science and Research in Contemporary Societies*, SAGE Publications Ltd, Los Angeles, CA, 1994.
[4] D.E. Stokes, *Pasteur's quadrant: basic science and technological innovation*, Brookings Institution, Washington DC, 1997.
[5] L. Alba-Lois and C. Segal-Kischinevzky, Yeast Fermentation and the Making of Beer and Wine, *Nature Education*, Vol. 3, 2010, 17.
[6] S. Cantrill, *The Sceptical Chymist*, 2019, https://chemistrycommunity.nature.com/posts/46994-speaking-frankly-the-allure-of-pasteur-s-quadrant , accessed: 25.03.2022.
[7] G.C. Banks, J.G. Field, F.L. Oswald, E. H. O'Boyle, R.S. Landis, D.E. Rupp and S.G. Rogelberg, Answers to 18 Questions About Open Science Practices, *J. Bus. Psych*., Vol. 34, 2019, pp. 257-270.
[8] O. de Lange, C. Youngflesh, A. Ibarra, R. Perez and M. Kaplan, Broadening Participation: 21st Century Opportunities for Amateurs in Biology Research, *Integ. and Comp. Biol.*, Vol. 61, 2021, pp. 2294–2305.
[9] L. Scheifele and T. Burkett, The First Three Years of a Community Lab: Lessons Learned and Ways Forward, *J Microbiol Biol Educ*. Vol. 17, 2016, pp. 81–85.
[10] S. Ravitch and N.M. Carl, *Qualitative Research: Bridging the Conceptual, Theoretical, and Methodological*. Sage Publications, Thousand Oaks, CA, 2016.

[11] Open Insulin Project, Open Insulin Foundation, 2020, https://openinsulin.org/ , accessed: 25.03.2022.
[12] J. Hargreaves and A. Frost/Health Care Institute, 2017, *Price of insulin prescription doubled between 2012 and 2016*, Accessed: 25.03.2022. [Online]. Available: https://healthcostinstitute.org/diabetes-and-insulin/price-of-insulin-prescription-doubled-between-2012-and2016
[13] N. Foti, *Community-based Insulin: An Urgent Response to Systemic Failures in the US Pharmaceutical Regime*, Othering & Belonging Institute, Berkeley CA, 2020.
[14] Real Vegan Cheese, https://www.realvegancheese.org/ , accessed: 25.03.2022.
[15] C. D'haeseleer, P. Juul, and M. Rouskey, Real vegan cheese, *BioCoder*, Vol. 4, 2014, pp. 71-77.
[16] C. E. Garciamendez-Mijares, P. Agrawal, G.G. Martínez, E.C. Juarez and Y.S. Zhang, State-of-art affordable bioprinters: A guide for the DiY community, *Appl. Phys. Rev*., Vol. 8, 2021, p. 031312.
[17] M. Kahl, M. Gertig, P. Hoyer, O. Friedrich and D.F. Gilbert, Ultra-Low-Cost 3D Bioprinting: Modification and Application of an Off-the-Shelf Desktop 3D-Printer for Biofabrication, *Front. Bioeng. Biotechnol*., Vol. 7, 2019, p.184.
[18] F. Koch, O. Thaden, K. Tröndle, R. Zengerle, S. Zimmermann and PeterKoltay, Open-source hybrid 3D-bioprinter for simultaneous printing of thermoplastics and hydrogels, *HardwareX*, Vol. 10, 2021, e00230.
[19] A.S. Munoz-Abraham, M.I. Rodriguez-Davalos, A. Bertacco1, B. Wengerter, J.P. Geibel and D.C. Mulligan, 3D Printing of Organs for Transplantation: Where Are We and Where Are We Heading?, *Curr Transpl Rep,* Vol. 3, 2016, pp. 93–99.
[20] BioCurious BioPrinter, Available: https://sites.google.com/site/bioprinterwiki/ , accessed: 25.03.2022.
[21] M. Salganik, The Wheels on the Bus, 2012, https://msalganik.wordpress.com/2012/10/07/pasteurs-quadrant/ accessed: 25.03.2022.
[22] J. Crawford, Pasteur's Quadrant, 2020, https://rootsofprogress.org/pasteurs-quadrant , accessed: 25.03.2022.
[23] T. Landrain, M. Meyer, A.M. Perez and R. Sussan, Do-it-yourself biology: challenges and promises for an open science and technology movement, *Syst Synth Biol*., Vol. 7, 2013, pp. 115-126.
[24] P. Collison and M. Nielsen, Science is getting less bang for its buck. *The Atlantic*, 2018, https://www.theatlantic.com/science/archive/2018/11/diminishing-returns-science/575665/ , accessed: 25.03.2022.