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Enterprise systems thinking applied to community biology labs

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Abstract

Community biology labs are locally organized spaces for research, tinkering and innovation, which are important for improving the accessibility of biological research and the transferability of scientific knowledge. These labs promote citizen science by providing resources and education to community members. For community labs to deliver consistent and reliable results, they would ideally be based on an adaptive and robust foundation: an Enterprise Systems Thinking (EST) framework. This paper follows a descriptive methodology to apply EST to conceptualize the optimal functioning of community biology labs. EST approaches can increase the overall understanding of the community lab system's context and performance. This supportive tool can aid in successful stakeholder engagement and communications within the lab's complex structure. It is also adaptive and can be adjusted as Community Bio labs expand in scale and are newly introduced to local communities. The result of this paper is the development of a framework that may help enhance existing community laboratory organizational approaches so that they may provide consistent accessibility, innovation and education to local communities.

Introduction

Community biology labs, also known as Do-It-Yourself (DIY) Biology spaces, are physical laboratories that allow community members to perform biological research and experiments, often centered on the molecular life sciences. These spaces typically provide access to essential laboratory equipment, materials and expertise while fostering an environment of collaborative learning and experimentation. Notable examples include Genspace and Biotech without Borders in New York City, and BioCurious and Counter Culture Labs in California, which serve as hubs for citizen science, biotechnology education and innovative research. These labs play crucial roles in democratizing science by offering workshops, hosting educational programs and supporting projects ranging from synthetic biology experiments to the development of sustainable technologies. Community biology labs occupy a unique position, operating as independent, volunteer-run, community-based organizations outside the usual scope of academia, government-run research facilities and private industry. They operate using the practice of open science, which involves making knowledge transparent and accessible to people at all levels of society, regardless of whether they are amateurs or professional scientists (Landrain et al. 2013). The strategic intent of community labs is to benefit local communities through accessible and decentralized means of scientific engagement and to promote openness and transparency in scientific education, exploration and innovation for the public good (Aldulijan et al. 2022).

Community labs face numerous challenges, the primary one being the fundamental problem of accessing funding, beginning with the initial hurdle of raising sufficient seed capital to start a community lab (Kuiken, n.d.). Their main source of funding is from private donors and institutions who support democratizing science through open community science labs (Golinelli and Ruivenkamp 2016). Most federal funding supports academic and governmental institutions at the federal or state level. Given the competitive funding climate for scientific research at established universities and institutions, community labs face exponentially larger fiscal challenges if private funding is insufficient for their activities.

Funding challenges can, in part be attributed to a general reluctance of government entities to financially support an open lab of perceived "non-scientists" (those who have not been formally trained or educated in scientific research). As the COVID-19 pandemic has shown, any breach in safety or compliance protocols, real or imagined, in a research lab often draws negative attention to the agency that funded the lab (Subbaraman 2020). Therefore, community biology labs must establish strict compliance with federal and state safety and containment protocols. This puts an additional financial need on community labs to dedicate resources to extensive training and outreach activities to establish greater credibility as legitimate research facilities (Scheifele and Burkett 2016; Lange et al. 2021).

Costs in the form of time and experience are yet another major challenge faced by community labs. A limited number of people with adequate expertise in the biotech field are willing to volunteer their time to work in a community setting and provide extensive guidance to non-traditional scientists. Community labs need the involvement of experts to provide advanced-level science education and technical guidance. Community labs must juggle engaging in the lab's work and building their participating expert networks. Every level of operation relies on an ongoing level of expertise and a strong commitment to the lab itself.

A third concern facing community labs is the availability of suitable space for conducting research. Like most enterprises, community labs must find a space that is affordable and relatively accessible to all community members. However, due to the activities that will be conducted there, community labs must balance those needs with local health and safety codes that may limit where a biotech lab facility can operate. Additional permits may be required from multiple oversight entities; this is a challenge that may be relatively easy and straightforward for established labs settling into a new space but can be monumental for the leadership of nascent community labs to overcome.

While all community labs face these common challenges, the spaces themselves are diverse with significant differences in structure and organization. This makes it difficult for labs to learn from one another and follow a successful lab's precedent while seeking solutions to their unique challenges. In addition, there is a lack of research on frameworks that could help community labs better organize themselves. This is where the application of Enterprise Systems Thinking (EST) engineering approaches could be useful. This approach can help community labs, despite their differences, to analyze their individual organizational structure to see where it is succeeding and where improvements could be made (Kuiken, n.d.; Golinelli and Ruivenkamp 2016).

Enterprise Systems involve the knowledge, principles and practices related to an enterprise's analysis, design, implementation and operation. It consists of interconnected information systems and/or technologies that work together to plan, control, coordinate and make decisions that achieve the overall goal of the enterprise. In fact, a central principle of enterprise systems is that an enterprise itself is regarded as a system. EST is an approach to problem-solving that uses subsystems, interactions, relationships and processes to produce a desired result (White 2021; Mason 2015). This type of approach is a method that can be used to evaluate any system of interest, including community biology labs. This paper uses EST to provide insight into the interactions and complexities of the functioning of community biolabs. The authors of this paper represent a community lab member (of Biotech without Borders and Genspace, New York City) and an Executive Director of a community lab (Baltimore Underground Science Space), who have organized collaborative activity meetings of the Global Community Bio Summit (the leading gathering of community lab participants and leaders). We use our extensive experience within community labs, to describe common features of community labs, their organization and their challenges before we describe how an EST strategy can address these common issues. Our goal is to conceptualize the optimal functioning of community labs using a descriptive approach to help community labs optimize their functioning to achieve their mission.

Methods

Our methodology is descriptive and consistent with approaches taken by others in the field (Mason 2015; Gorod et al. 2014). We first define the characteristics of an Enterprise System. We then use an autoethnographic approach to apply this framework to the community bio labs based on our own experience with community labs. Our work is organizational-focus, it does not utilize human subjects and therefore does not require ethical approval or focus group. Finally, we use this framework to understand commonalities in community lab structure and function that can help labs chart their optimal development and share best practices. Our methodological framework centers on the definition of an "enterprise" as an intentional cooperative of people who come together with a shared societal purpose. Characteristics of a well-defined enterprise have been previously defined and include:

1. an integrated "System of System" that is centrally directed and designed to fulfill specific purposes
2. stages of engagement, integration and delivery
3. variation in the integration and delivery steps depending on the context of the project
4. viewing people as an actual component of the system rather than as users or operators
5. viewing people as an actual component of the system rather than as users or operators
6. viewing the enterprise as an adaptive agent, capable of learning and maturing over time with continuous response and adaptation
7. ability to be subdivided into groups such as organizations, people, technology, hardware, software, storage and communications.

Results

Using EST to understand community lab structure

Community labs can be viewed as a form of social enterprise and as such could benefit from a Social Enterprise System approach to their architecture, functions and processes. This approach allows labs to build a consistent framework of repeatable outcomes. It also allows for continuous improvement by revealing gaps in functioning and outlining a reliable approach to positive outcomes. Our model of a community lab as an Enterprise System is depicted in Figure 1 and consists of three main phases: Engagement, Integration and Delivery.

Engagement

Community labs occupy a unique – and rather unusual – role in general science education, scientific research and open innovation. Community labs function as independent communal spaces with in-house laboratory equipment where community members can conduct independent research investigating a wide range of topics of interest. Bio lab communities are in a unique position to actively challenge popular perceptions of who should practice science by uniting a diverse range of participants from various backgrounds and walks of life. These spaces promote networking, open collaboration and sharing of skills and knowledge between amateur scientists, hobbyists, tech enthusiasts, under-represented groups and professional scientists. Providing accessible science education opportunities to so many depends on successful engagement methods to bring together volunteers, space and

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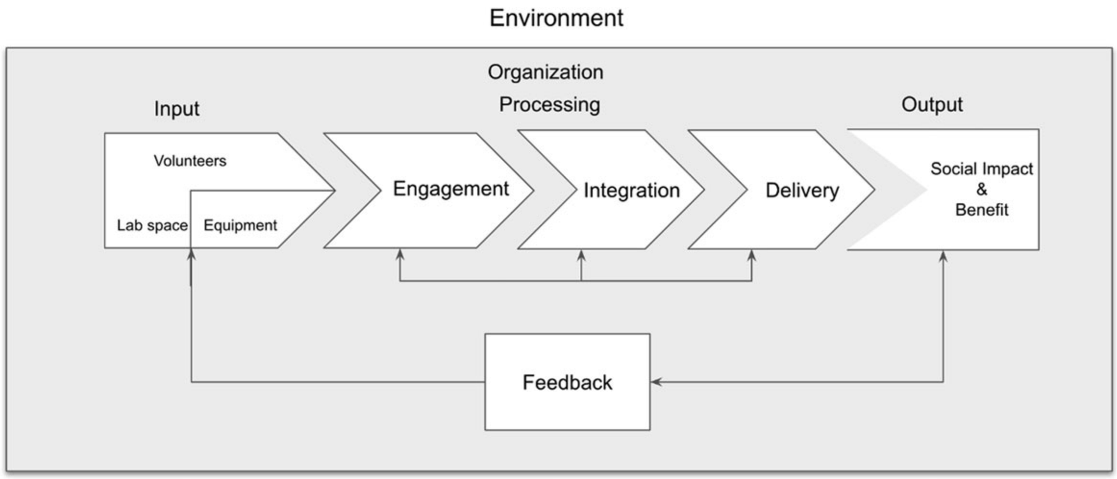

Figure 1. A simplified Community Bio Lab EST model with three phases: engagement, integration and delivery.

equipment/tools (Figure 1). Active processes for outreach and fostering an ethos of openness are essential components central to the philosophy of community labs. The governing body's outreach must be designed to engage various stakeholders, build networks and collaborate with local communities, universities, industries and private donors (Saint-Onge and Wallace 2012). Events like The Global Community Bio Summit (https://www.biosummit.org) provide a space for sharing advances in the community bio movement and output from community bio labs worldwide each year.

Community labs often operate on the principles of open design, open intellectual property (IP) and with shared hardware. They are created to promote the democratization of knowledge and seek to promote the free and open sharing of original research. Community members can tinker with prototypes, modify earlier projects developed by other community members, improve upon existing technologies by making them simpler to use or cheaper to produce and engage openly and collaboratively on projects. Community labs promote user-centered innovation where the primary focus is adapting or otherwise modifying prototypes to suit the unique needs of the end user. In addition, the open environment of community labs may help create more ethical spaces for synthetic biology (Golinelli and Ruivenkamp 2016; Meyer 2013).

An example of an established community science project that embodies these principles of open sharing and design is Open Insulin, which began as a community initiative and evolved into the Open Insulin Foundation, a research project aimed at making insulin more accessible and less expensive for those who need it. Through this project, community lab members come together in search of solutions to the commercial monopoly on insulin production (Gallegos et al. 2018). Another community lab project, Real Vegan Cheese, aims to make dairy products from the cloned casein genes of diverse organisms, which can be turned into cheese using a traditional cheese-making process. Counter Culture Labs in Oakland, CA, and BioCurious in Sunnyvale, CA. have demonstrated how citizen science can lead to impactful ventures, as exemplified by two notable projects (D'haeseleer, Juul, and Rouskey 2014; Aldulijan et al. 2022).

Many community lab members have joined an effort known as the Open COVID-19 Initiative. This initiative consists of a large collaboration using the online "mobilization platform" JOGL (Just One Giant Lab) and seeks to develop affordable, open-source tools and methodologies that may be safely and easily used in response to the COVID-19 pandemic. Community labs also engage with communities in synthetic biology competitions like International Genetically Engineered Machines. These events create opportunities for the labs to mentor and support high school and community teams. One notable example of a start-up that emerged from a community biology lab is OpenTrons, which originated from Genspace in New York City. OpenTrons developed affordable and easy-to-use robotic pipetting systems; today, OpenTrons is a major player in biotech automation, providing valuable tools to labs. This case exemplifies how community biology labs can serve as incubators for innovation, transforming ideas into impactful biotech start-ups. These engagement types with communities build support for labs and encourage open collaboration to solve universal problems. Engaging partners who can commit to the shared ethos of open science and community commitment is, therefore integral to community lab engagement strategies (Aldulijan et al. 2022).

Integration

The integration phase represents the practical manifestation of the community lab's mission, incorporating elements of support, management and resources. It includes the design process in which the context of the project and community application is defined. The environment and strategic imperatives are identified. Roles and responsibilities for community members can be assigned, and the project's deliverables and tangible outcomes to be measured can be set. Importantly, the knowledge-sharing culture can be individually characterized for each community lab in this process, and the project management approach can be outlined and established (White 2021; Saint-Onge andWallace 2012; Unger and Polt 2017).

As depicted in Figure 2, the integration process can be visualized as iterative steps that refine the final design of the community project. One side of the process utilizes cycles of inquiry and evaluation to inform on the social responsibility of the design. As new ideas or situations are presented to the community, they are evaluated and accepted as is, or are modified, discarded, or expanded upon. A collective voice begins to form as the community's personality develops. This information then feeds into the build and test side of the process. In this arena, the initial

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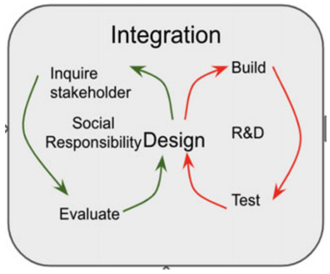

Figure 2. Integration involves iterative cycles between two phases to improve the design: a research and development cycle of building and testing (red) informed by the social responsibility cycle of inquiry and evaluation (green).

design is refined through research and development to the final implementation point. Community lab members build prototypes which are to be assessed in the testing phase. The main focus is on the logistics or the project phase of community development – putting the foundational pieces into place on which the community will be built (Saint-Onge andWallace 2012; Whitford, Lübke, and Rückert 2018). Smaller objectives can be developed within each of the actions of this cycle. Continued iterations of the process provide opportunities to reflect on what works well within the system and what needs to be reconsidered in future community development projects. Key issues and lessons learned can be identified through this process in a way that is structured and reproducible. Continuous cycles through this model allow development, evaluation and growth to interact dynamically.

The integration model involves two different populations in each of the cycles. In the research and development phase, the majority of the decisions are made by a handful of people, and the project manager controls the process of putting the infrastructure into place. In the inquiry phase, community members are in the driver's seat. Facilitation keeps the community moving forward, but the ultimate direction is in the hands of community membership (Saint-Onge andWallace 2012; Unger and Polt 2017; Chaupis-Meza 2018). In the evaluation phase, community members incorporate feedback received through inquiry to improve the project design. As evaluations can be quite subjective if defined only by the leaders of individual community labs, we have provided a framework in which evaluation can be applied more broadly to a range of labs with varying projects. The evaluation of the merits of any given project will be guided by the principle of Human Practice, where each community biology lab will carefully consider the ethical, environmental and societal implications of every phase of development for each project. Considering the substantial support community biology labs need to operate, constant reflection on the project's social responsibility is as essential as the research and development of the design itself (Whitford, Lübke, and Rückert 2018).

Delivery

The delivery process encompasses the implementation of a successful project within the community and consists of three components: research, open innovation and education. These are collectively known as the knowledge triangle and are key drivers of a knowledge-based society (Unger and Polt 2017; Chaupis-Meza 2018). These components entail the outputs and outcomes of the activities engaged by the community lab. The positive effects of community labs' research, innovation and education efforts provide the community a social return on investment. The community biology lab movement in the United States traces its origins to 2010 with the establishment of Genspace in Brooklyn, New York, which became the first publicly accessible biosafety level one laboratory dedicated to citizen science. Since then, the movement has grown in large cities across the United States, supported by various funding mechanisms, including federal grants from the National Science Foundation and local funding, particularly through their broader impacts and science education initiatives. These labs operate under the oversight of federal regulations, including NIH Guidelines for Research Involving Recombinant or Synthetic Nucleic Acid Molecules, and also voluntarily follow the DIYbio codes of conduct established at the 2011 North American Congress for Safe and Responsible Citizen Science.

All knowledge and data generated by researchers working in the community lab often remain open source or freely available to other researchers and accessible to the general public as open IP (Landrain et al. 2013; Meyer 2013). Community labs provide an arena to close the innovation divide, which is the gap that exists between the latest research knowledge and real-life practice. In industry, fears regarding ownership of exclusive IP rights conspire to stifle open discussions and collaboration. In academia, scientific research is heavily influenced by pressures placed upon researchers to secure grants and publish their work in high-impact journals. Funding agencies and academic journals tend to focus on a restricted range of topics, thereby stifling innovation by leading scientists to favor research that is likely to be funded and has a better chance of being published as opposed to pursuing radically different and innovative ideas. Community labs offer alternative spaces where scientists can focus on innovative research without the usual pressures to conceal original results, quickly publish their work in journals, or secure patents. There is significant potential to accelerate innovation when community labs are given the chance to function as incubators to help close the innovation divide (Kera 2014).

Community labs seek to bridge scientific education, literacy and access gaps. They strive to accomplish this by sharing knowledge and expertise between academic scientists, industry researchers, students and interested community members and providing access to anyone interested in biotechnology (Landrain et al. 2013; Keulartz and Belt 2016). Community labs engage in community education and outreach, cultivate young people's interest in biology and other STEAM fields and encourage participation from traditionally under-represented groups and minorities (Lange et al. 2021). They help demystify scientific research and innovation for the curious layperson and counteract the growing public distrust of science by increasing public scientific literacy and facilitating non-scientists' involvement in science-related projects and open conversations with researchers (Unger and Polt 2017; Chaupis-Meza 2018).

Discussion

Systems theory is a scientific approach to understanding all types of systems – from biological and ecological to conceptual. Systems thinkers view most systems as living (open) systems, moving towards order and complexity (Cabrera and Cabrera 2019). The biggest benefit of approaching community lab structure with systems thinking is that it allows labs to build a consistent framework of repeatable outcomes and continuous improvement by revealing gaps in function and outlining a reliable approach to positive outcomes. A systems thinking approach will allow the

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community lab governing body to better analyze the relationships between the various stakeholders involved and the elements influencing the community lab as an open social enterprise system. Systems thinking also provides a set of tools to the designer so the problems and complexities of a situation can be revealed and managed appropriately (White 2021; Mason 2015; Keulartz and Belt 2016).

The success of community biology labs in fostering innovation and supporting start-ups depends on several critical factors that align with Enterprise Systems Thinking principles. At the infrastructure level, these labs must provide access to specialized equipment, adequate laboratory space for prototype development, proper safety and containment facilities, quality control systems, regulatory compliance, safety standards adherence and liability considerations to ensure responsible innovation. Support emerges as another crucial element, with community labs offering structured mentorship programs, extensive network access, diverse funding opportunities and valuable industry connections. This support system is enhanced through meaningful community integration, where labs maintain open science principles, establish clear knowledge-sharing protocols, prioritize community benefits and sustain educational outreach programs.

For community biology labs specifically aiming to support start-up development, several key recommendations emerge from our analysis. First, structured incubation programs can be established, featuring mentorship, business development resources, legal guidance and networking opportunities. Second, IP policies can be implemented, including well-defined innovation ownership guidelines, collaboration agreements, technology transfer protocols and revenue-sharing models. Third, resource allocation strategies should be developed, encompassing equipment access policies, space utilization guidelines, cost sharing structures and support service availability. Through these structured approaches, community biology labs can effectively balance their role as innovation incubators while maintaining their core mission of democratizing science and serving their local communities. These elements collectively create an ecosystem that balances innovation with community responsibility.

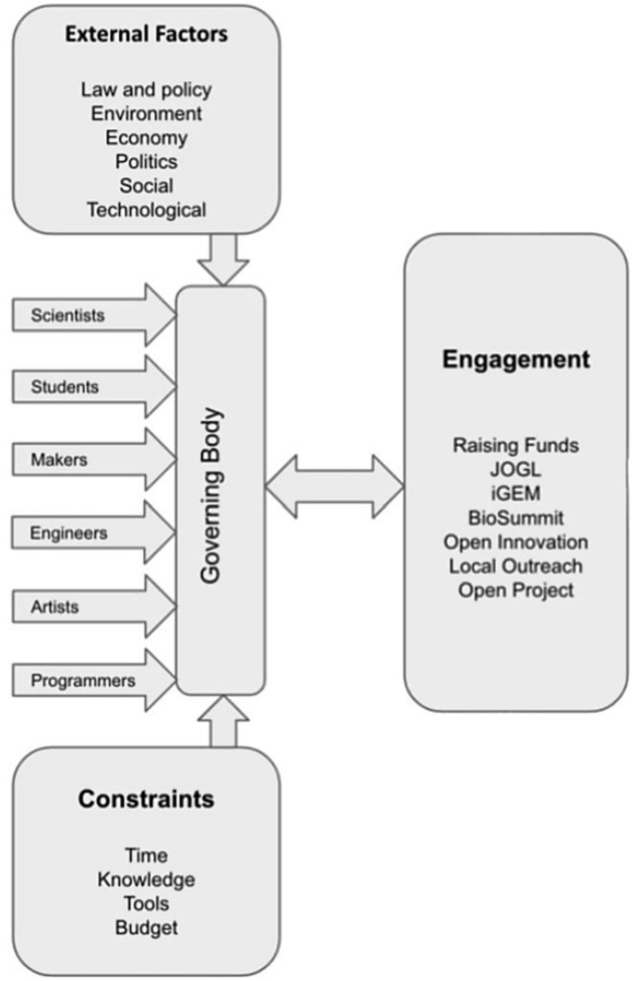

Figure 3. Community lab governance involves inputs from all types of members (yellow arrows, left). Constraints and external factors also dictate the scope, roles and function of the governing body. Engagement with the community at large through outreach events like iGEM creates a bidirectional flow of information that influences the path of the community lab: the governing body must perform the outreach events to sustain the lab, and the outreach events inform the governing body of the values of the community, putative new members and cutting-edge projects of interest for the future.

The governing body

Central to this management process is organizational governance, consisting of the decisions and actions of the people who run an organization, city, or nation. Effective governance is needed for the success of any enterprise and it is essential for the organization to achieve its objectives and improve, as well as to maintain legal and ethical standing for stakeholders and the general community (Bevir 2012). Community lab governance can follow one of several different general models and may be hierarchical and formal or collaborative and open. Both models are seen among different community lab organizations. Community labs may be led by either the private sector, the public sector, or public-private partnerships. Community lab spaces may be for-profit, non-profit, or informal. In formal governance structures, the management or directorial board holds different responsibilities (e.g., managing finances). Some community labs promote the involvement of members by hosting meetings where discussions over governance occur.

Regardless of its form, community lab governance is important because it ensures transparency and ensures that the interests of both majority and minority stakeholders are safeguarded. Community lab governance affects the operational risk and thus the sustainability of the lab; its objective is to determine the policies and processes by which the labs will operate transparently to increase the long-term value for lab communities. The governing body is the catalyst for the inflow of volunteers to engage, integrate and deliver to the rest of the outflow. Community lab governance processes are shown in Figure 3 and depict how constraints and other external and internal factors influence the governing body's work. The governing body has a major role in recognizing the needs of community labs. It is responsible for the general operations of each community lab, ensuring compliance with regulatory agencies, drafting ethical and safety guidelines for the community to follow, procuring funding, supplying needed laboratory equipment, engaging with donors and audiences that are likely to be interested in funding the projects and activities being conducted by the community lab and engaging in general project coordination and other practical supports as needed. Partnerships must be formed with domain-specific experts and those with diverse skills who share the desire to coordinate project activity to meet the organization's goals (White 2021).

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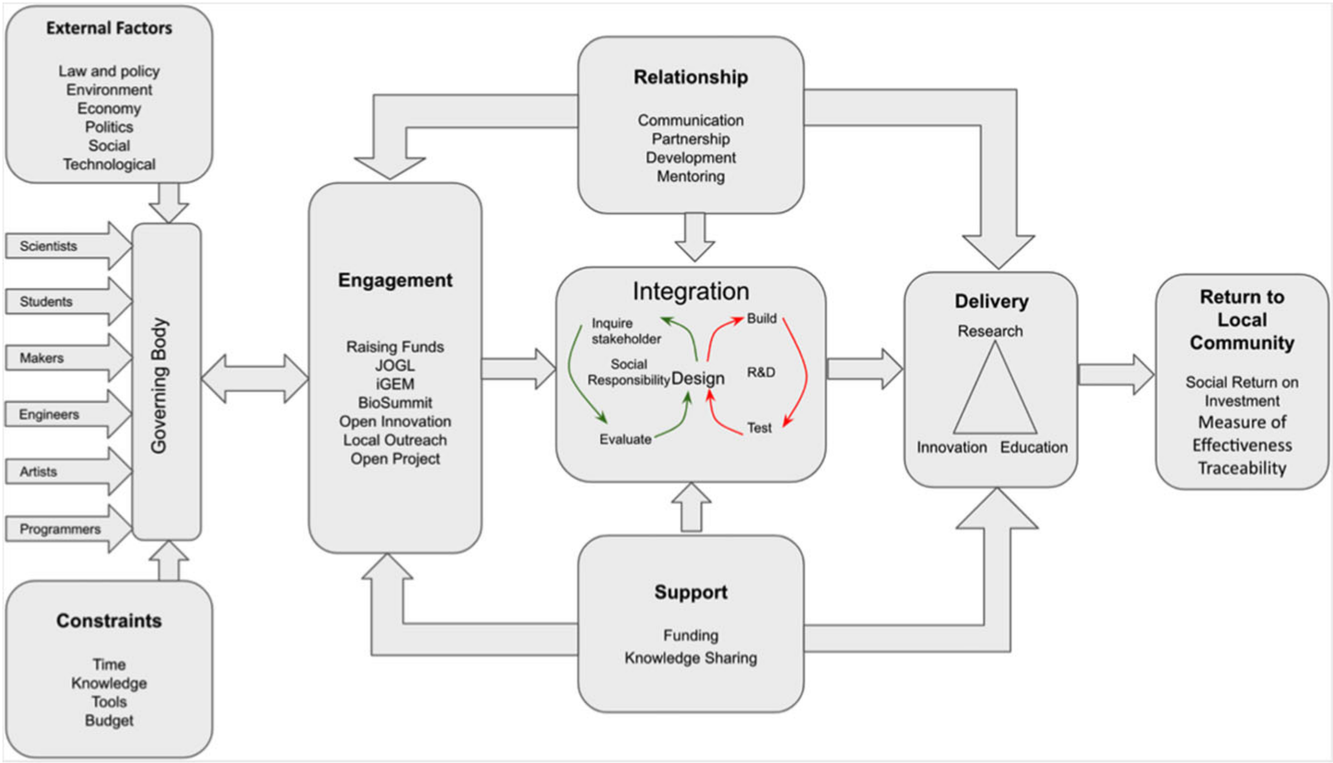

Figure 4. The complete Open Engagement Enterprise for Community Labs shows the phases of engagement, integration and delivery. Relationships with the community enhance engagement activities, provide resources for the integration phase and enable broader participation in the delivery phase. Support allows all phases of Community Lab functioning to thrive. The final result of the Enterprise is a return to the local community through social and investment benefits.

The question of who decides which projects the community lab takes on often rests with the individual spearheading the project, in collaboration with the governing body. Everyone who is established to lead the project can also make decisions on which projects are undertaken. Different strategies may determine how these decisions are made. For instance, the project proposer or board of the governing body may decide, or the volunteers may decide by consensus, or the volunteers may decide by majority rule (Saint-Onge and Wallace 2012). A healthy community lab relies upon open and transparent communications between the governing body, volunteers, community members and stakeholders.

Relationships with outside groups

To maintain operations, a community lab requires various types of technical and financial support to build its operational capacity. These types of support include addressing administrative needs, supplying access to appropriate equipment, and offers of volunteer time and knowledge to the community. Other forms of support include knowledge and resource-sharing through platforms such as GitHub and communal DNA repositories (BioBricks, Addgene).

Community labs will often reach out to academia and industry to foster collaborative networks and partnerships (Whitford, Lübke, and Rückert 2018). In addition, they offer a unique opportunity for individuals from diverse educational and professional backgrounds to exchange ideas about science, technology and ethics. The Yale School of Medicine recently launched its community training program BioLaunch, a collaborative educational internship targeting young adults who are not pursuing a traditional 2- or 4-year university degree. The state funds the program but has partnered with local biotech companies to provide internships for BioLaunch graduates at the completion of their training (Yale School of Medicine 2023). The value of knowledge, experience and inspiration from community lab members is receiving recognition from industry leaders. The Life Sciences Supermind Report was created from a summit of global thought leaders assembled by the MIT Center for Collective Intelligence, the MIT Media Lab's Community Biotechnology Initiative and MilliporeSigma. This report contains insights and proposed solutions to pressing problems in global health; notably, the most recent report published in 2021 focused on solutions to address future pandemics based on lessons learned during the COVID-19 pandemic (MIT Center for Collective Intelligence and MIT Media Lab 2022). Through these kinds of exchanges, communities stand to benefit from the unique perspectives that people from both inside and outside the field of molecular biology can offer.

As non-profit organizations, community labs rely on fundraising in order to pay for rent, laboratory expenses, educational outreach and research projects. Successful fundraising improves the viability of community labs' engagement and should be considered in the early stages of projects. A variety of funding sources are available for bio lab communities. Some sources include grants provided by private philanthropic organizations and gifts from generous individual donors. Other funding sources include partnerships with start-ups to deliver original prototypes and technologies developed in the lab to wider markets and capitalize upon the profits generated. Community labs may also collect membership fees and charge tuition for workshops, courses and seminars. Further funding opportunities include microgrants, crowdsourcing and building relationships with foundations and

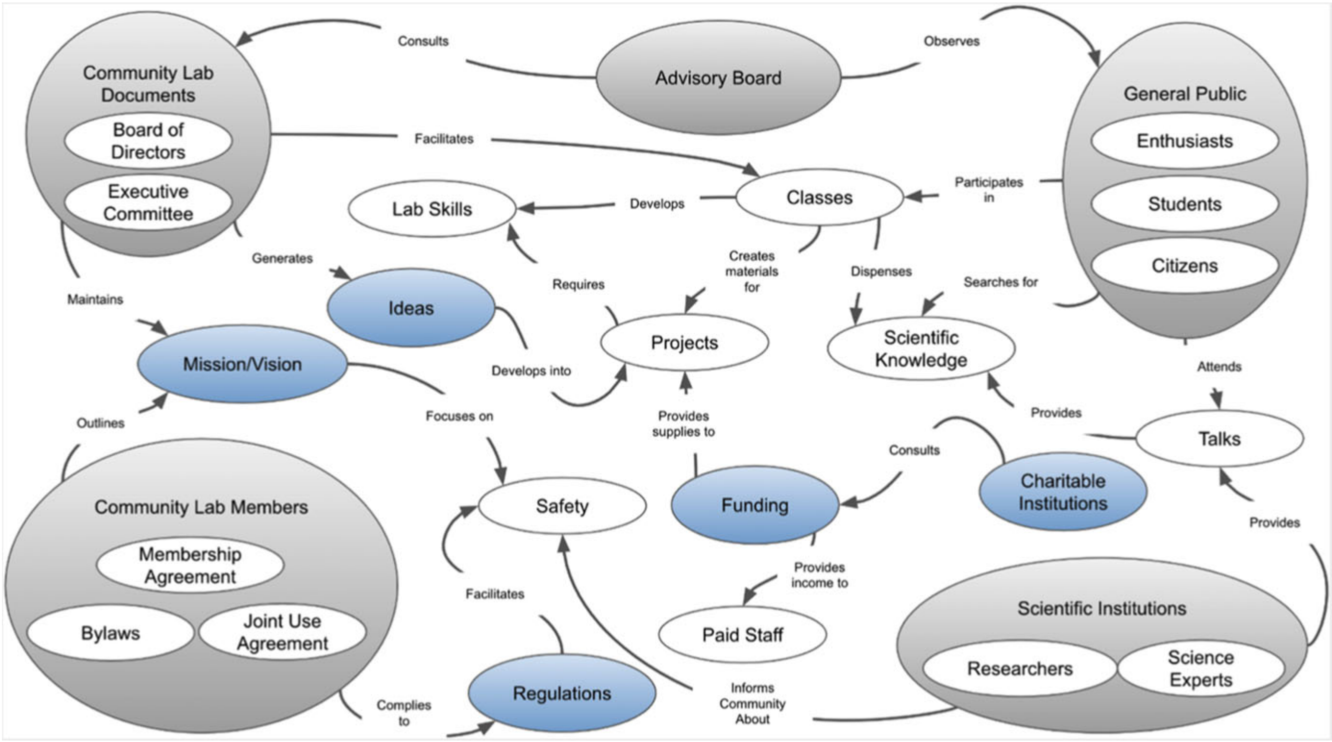

Figure 5. Community Biology labs as a complex system.

schools where donations of equipment and training time may be donated on an in-kind basis.

Forming relationships is a crucial step in achieving the goals of engagement, integration and delivery of scientific advancement, which help integrate the scientific community of the lab into the community at large. Community labs must be diligent in cultivating mutually beneficial relationships. Community labs benefit from establishing a wide network of partnerships with diverse stakeholders to meet practical needs. Such partnerships can provide access to donors, reliable sources of funding and individuals with professional-level knowledge and expertise. Partnerships may also provide access to individuals who are willing to volunteer their time and energy and share their expertise with the lab community. Friendly relationships with science departments of local colleges and universities can provide practical aid to the community lab. For instance, such local colleges and universities can donate old or unwanted laboratory equipment or donate time and expertise from academically trained individuals (Kuiken, n.d.; Meyer 2013; Chaupis-Meza 2018).

Support systems

Community labs conceptualize knowledge as being communal and relational, and endeavor to exist as Communities of Practice (Saint-Onge and Wallace 2012). Community labs provide young people with mentors and role models, host youth programs and motivate people from under-represented backgrounds to feel more confident pursuing education in the STEAM fields and future careers in the sciences. Lab-based Communities of Practice frequently provide extensive mentorship, training and networking opportunities for local entrepreneurs and beginner biotechnology "tinkerers." Community labs help these individuals by providing opportunities to hone technical skills and expand their knowledge through a combination of informal interactions with members of the community lab. These interactions are typically comprised of fellow biotech enthusiasts, professional researchers and entrepreneurs and occur through specialized courses and workshops provided by the community lab.

Beyond training and mentoring for young scientists, community labs also provide support and education for others who wish to learn more about science or how to apply scientific principles to their work. Biotech Without Borders is a non-profit public charity founded by Dr. Ellen Jorgensen, who previously co-founded the seminal community lab Genspace. One of their programs provides education and training to local STEM teachers, providing a space for them to prepare and practice labs that can be incorporated into their curricula to expose students to molecular biology. They also offer training to teachers in the Math for America program to incorporate biotechnology into their classrooms (BiotechWithout Borders, Accessed 2023).

Conclusions

This paper provides a general overview of community labs and the applicability of enterprise thinking and enterprise systems models to improve the functioning and integration of community labs into the current academic and industrial scientific landscape. Enterprise thinking delivers a robust framework for investigating and implementing solutions to common problems faced by community labs, such as funding, support, time commitment, expertise and available space. Our Open Engagement Enterprise for Community Labs is depicted in Figure 4. This framework contributes to existing research by providing a specific method by which labs can improve their organization when viewed as a complex system, as shown in Figure 5. The framework is a means to adapt to the changing landscape the DIY-biology and

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community labs will find themselves in as perspectives shift on their role in scientific research. It can also be viewed as a simplified roadmap to community labs, illustrating the iterative process of managing labs: member engagement and project design, output and feedback from the community. The framework accomplishes several goals: First, lab governance can readily note the various external factors and constraints acting upon the lab space; second, governing bodies can analyze the available supports and relationships and better understand the system of engagement, integration and delivery between community members and collaborators working on research projects; and finally, this framework allows the governing body to assess and measure the social impacts of a given community lab upon the local community and society at large. A common problem many start-up labs may face is establishing a robust operating framework to protect contributions from investors and regulate lab operations while keeping the lab atmosphere open to volunteers and interested parties. Our framework shows where each member can fit into the system; governance goals and functions are separate from those in the actual R&D phase and thus, different members will enter the system in an area appropriate for their role. Applying a systematic approach to planning and improving community labs is essential for them to deliver the desired results of innovation, education and research in a timely and cost-effective manner.

Formal scientific training is not a requirement to participate in a community biology lab project. In fact, many community labs encourage participation from so-called non-traditional scientists to expand the scope and diversity of ideas and experiences being brought to the lab space. However, as is often true for academic scientists, lack of formal training often means a lack of exposure to the nontrivial processes enabling the lab to operate. Many complex system components can be overlooked or inappropriately approached when undertaken by members with no experience in these areas. Our EST framework for lab governance and operation provides the basic blueprint for tackling all the problems community lab leadership face in managing their projects. This framework should be implemented to aid community labs in overcoming obstacles so that they can better serve their community and humanity at large.

Data availability statement. All relevant data and references were included within the submission. Data sharing is not applicable to this article.

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