Inclusive Innovation in Biohacker Spaces: The Role of Systems and Networks

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> *"If, as I believe that my theory is true & if it be accepted even by one competent judge, it will be a considerable step in science."*
>
> Charles Darwin (1809–1882)
> Naturalist, geologist, and biologist
> In a letter to his wife, Emma, July 5, 1844

In this article, we examine the development of biohacker spaces and their impact on innovation systems through the lens of inclusive innovation. Examining issues associated with people, activities, outcomes, and governance, we observe that biohacker spaces offer an alternative approach to biotechnological research outside the orthodox walls of academia, industry, and government. We explain that harnessing the full innovative potential of these spaces depends on flexible legal and regulatory systems, including appropriate biosafety regulations and intellectual property policies and practices, and organic, community-based social and financial networking.

Introduction

The biohacking movement is changing who can innovate in biotechnology. Driven by principles of inclusivity and open science, the biohacking movement encourages sharing and transparency of data, ideas, and resources. As a result, innovation is now happening outside of traditional research labs, in unconventional spaces – do-it-yourself (DIY) biology labs known as "biohacker spaces". Labelled like "maker spaces" (which contain the fabrication, metal/woodworking, additive manufacturing/3D printing, digitization, and related tools that "makers" use to tinker with hardware and software), biohacker spaces are attracting a growing number of entrepreneurs, students, scientists, and members of the public.

A biohacker space is a space where people with an interest in biotechnology gather to tinker with biological materials. These spaces, such as Genspace (genspace.org) in New York, Biotown (biotown.ca) in Ottawa, and La Paillasse (lapaillasse.org) in Paris, exist outside of traditional academic and research labs with the aim of democratizing and advancing science by providing shared access to tools and resources (Scheifele & Burkett, 2016).

Biohacker spaces hold great potential for promoting innovation. Numerous innovative projects have emerged from these spaces. For example, biohackers have developed cheaper tools and equipment (Crook, 2011; see also Bancroft, 2016). They are also working to develop low-cost medicines for conditions such as diabetes (Ossolo, 2015). There is a general, often unspoken assumption that the openness of biohacker spaces facilitates greater participation in biotechnology research, and therefore, more inclusive innovation. In this article, we explore that assumption using the inclusive innovation framework developed by Schillo and Robinson (2017).

Inclusive innovation requires that opportunities for participation are broadly available to all and that the benefits of innovation are broadly shared by all (Centre for the Study of Living Standards, 2016). In Schillo and Robinson's framework, there are four dimensions along which innovation may be inclusive:

1. The people involved in innovation (who)
2. The type of innovation activities (what)
3. The range of outcomes to be captured (why)
4. The governance mechanism of innovation (how)

More particularly, inclusive innovation policy must consider historically excluded groups (i.e., women, youth, and informal sector entrepreneurs) as well as groups predicted to be negatively impacted by innovation (i.e., people with jobs that are predicted to be replaced by artificial intelligence) (Schillo & Robinson, 2017). Inclusive innovation requires considering activities not just in the economic sphere but also in the social sphere (European Commission, 1995; see also Planes-Satorra & Paunov, 2017). It also requires considering all positive and negative outcomes of innovation, such as economic, social, and environmental aspects (Kuhlmann & Rip, 2014). Lastly, inclusive innovation requires developing a governance mechanism that allows the inclusion of excluded groups as stakeholders in the innovation process (Schillo & Robinson, 2017).

In assessing the inclusivity of biohacker spaces, we have developed a concentric model, as depicted in Figure 1. The concept of space is at the centre of our analysis. Space is important for biohacking because physical location matters. In that respect, biohacking is more analogous to hardware engineering than software programming. Unlike software programming, where coders can collaborate asynchronously across vast distances, hardware engineering usually requires access to a physical space with tools and equipment beyond just a computer. That is also true for biohacking. The space for biohacking can take on different forms. It can be large or small, and range from a garage, bedroom, or kitchen to a biology-oriented community lab.

Four Dimensions of Inclusivity

In this part of the article, we examine the four dimensions of inclusive innovation in quadrants clustered around biohacker spaces. The four dimensions of inclusive innovation overlap to some extent with the three types variables used by de Beer and colleagues (2017a) in a recent scan of South Africa's maker movement. They looked at three clusters of variables – management variables, spatial variables, and activity variables – oriented around communities of practice. In our application of Schillo and Robinson's (2017) framework, biohacker communities can be understood in relation to the context of the inclusiveness of people as well as through other dimensions of inclusivity.

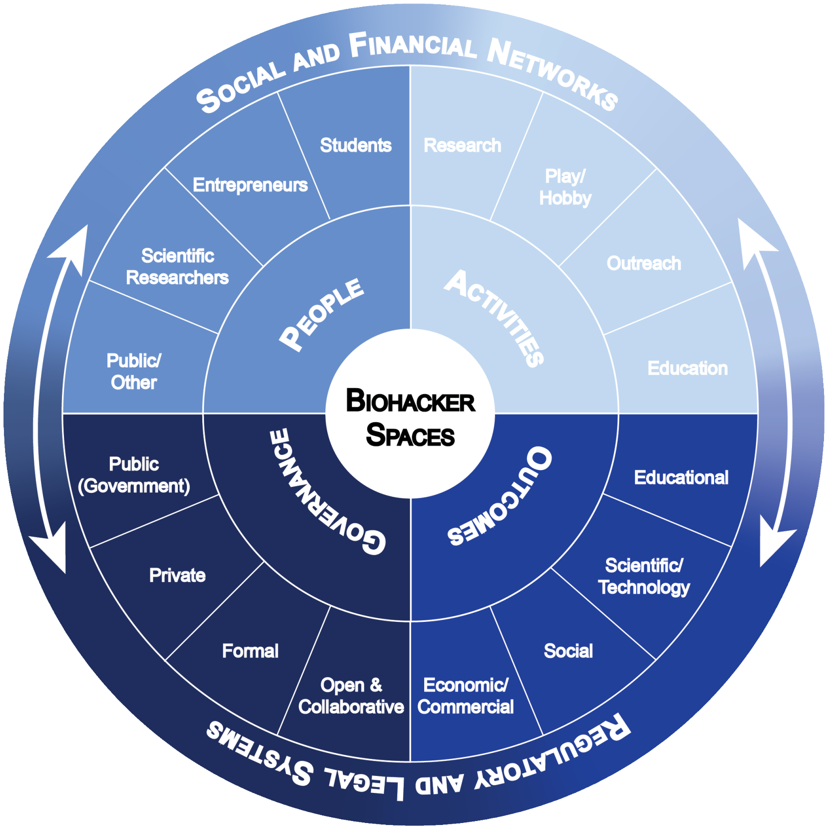

Figure 1. Context and constraints for inclusive innovation at biohacker spaces

Below, for each of the four dimensions illustrated in Figure 1, we explain some of the diverse traits of biohacker spaces that make them more or less inclusive. Of course, because every biohacker space is unique in some way, our analysis is illustrative not definitive. We then look at two broader characteristics of the innovation ecosystem, as opposed to biohacker spaces themselves, that we suggest especially impact inclusivity: social and financial networks, and legal and regulatory systems.

People

Biohacker spaces open a new possibility of participating in biotechnology to people in fields outside of formal, academic, or industrial scientific research. In contrast to academic labs, biohacker spaces usually provide access to everyone, regardless of their expertise and academic background (Landrain et al., 2013). They offer tools, resources, and training that benefit a diverse group of people: from students, to scientific researchers, to entrepreneurs, to members of the public simply interested in working creatively with biology (Meyer, 2012). With greater access, artists and designers can also use the technology and think of their own ideas, which may be different from what major companies do (Landrain et al., 2013). In these ways, the communities of people who use biohacker spaces are different than the communities who work with biotechnology in the conventional triple-helix innovation system involving university, industry, and government settings.

Activities

The activities that take place in biohacker spaces can be diverse, but we have classified them into four general categories: research, play/hobby, outreach, and education. Biohacker spaces give individuals a place to engage in scientific research; they also allow curious minds to play and tinker with biotechnology (Landrain et al., 2013). Spaces such as DIYBio Toronto (diybiotoronto.com) are committed also to public science education, and host events to engage citizens in biotechnology. Some spaces, such as Genspace in New York, host regular crash courses geared towards teaching amateurs the fundamentals of biohacking. In all of the activities of biohacker spaces, there are aspects of either formal or informal skills training, which help to make these spaces more inclusive.

Outcomes

Biohacker spaces may be associated with economic, social, scientific, and educational outcomes. On an economic level, biohacker spaces facilitate entrepreneurship by providing tools, training, and resources to help people prototype their biotechnology-based ideas. Biohacker spaces also help advance scientific research. There are many examples of ambitious projects that have derived from these spaces such as vegan cheese protein (D'haeseleer et al., 2014), genetically engineered bacteria that can sense arsenic (iGEM UCL, 2012), as well as robots that can automate lab work (OpenTrons, 2015). These projects have the potential to produce new breakthroughs in science. Socially, biohacking enhances public interest in biotechnology. A space itself can foster creativity and allow an exchange of ideas by allowing individuals of different experiences and expertise to meet and collaborate on projects. On an educational level, biohacker spaces help train individuals in biology and can improve individual skills through hands-on learning.

Governance

The governance of biohacker spaces may follow one of several general models. Governance may be formal and hierarchical, or it may be open and collaborative. It may be led by the private sector (i.e., corporate, community, or non-governmental organizations), the public sector (i.e., municipal governments or university), or public–private partnerships. Biohacker spaces may include for-profit, not-for-profit, as well as informal spaces (see Scheifele & Burkett, 2016). Spaces that are not-for-profit or for-profit are also impacted by their formal governance structures, such as executive management or a board of directors. The management or board itself may have responsibilities, such as handling the space's finances. Some spaces, such as DIYbio Toronto, enable member involvement in governing the space by hosting member meetings, where discussions regarding the space happen in person.

Globally, many spaces identify open science as a governing principle of their space (Delfanti, 2013; see also Delfanti, 2011). Open science encourages researchers to share data, ideas, and resources as a means to accelerate research without the restrictions imposed by the intellectual property (IP) system (Gold, 2016). In the open science model, "original discovery is rewarded with monetary and societal benefits, which create incentives for full disclosure and diffusion for scientific knowledge" (Merton, 1973). The open science model contrasts with the proprietary model of research that more traditional institutions tend to support (David & Hall, 2006). The less inclusive proprietary model is one where exclusive property rights are seen as incentive for investments in science (de Beer, 2017). By comparison, spaces such as Genspace and Biocurious (biocurious.org) do not own any patent rights to discoveries made in the lab (Burke, 2011). Neither do they restrict projects that might lead to patentable inventions (Burke, 2011). Of course, those spaces' practices may not be universal, particularly as commercial interest in the discoveries, inventions, and innovations arising from biohacker spaces increases.

Contextualizing Biohacker Spaces within the Innovation Ecosystem

Having considered the characteristics of biohacker spaces, we now explore the relationship between biohacker spaces and other aspects of the innovation ecosystem that can make these spaces more or less inclusive.

Innovation emerging from biohacker spaces falls, typically, within the realm of "user innovation". User innovation is distinct from open innovation, although the terms are often but mistakenly used synonymously (de Beer, 2015). Open innovation, as Chesbrough (2006) describes, refers to inward and outward flows of knowledge across organizational boundaries. This innovation model tends to rely on the appropriation and exploitation of IP. In contrast, user innovation, as von Hippel (2005) defines it, is in "sharp contrast" to the traditional innovation model in which manufacturers rely on patents, copyrights, and other IP rights to protect, and then exchange, products and services. User innovation refers to products or services developed by individuals or firms to use themselves (von Hippel, 2005). von Hippel's most recent work on "free" innovation contextualizes user innovation within ecosystems that support the unrestricted flow of innovation (von Hippel, 2016). Closely tied to the concepts of user innovation and free innovation is peer production. It describes decentralized, collaborative, non-proprietary production of knowledge (Benkler, 2006).

The concepts of user innovation, free innovation, and peer production aptly describe the approach biohacking adopts. Biohackers are interested in developing new products to use themselves. They value collaboration and data sharing without the limitations imposed by proprietary models of innovation or regulatory constraints. At the same time, we argue that successful peer production depends on social networks in which the activities people engage in are connected by common values. And while "free" innovation may not come with market prices, every activity has some kind of associated direct, indirect, or opportunity costs.

These concepts raise important questions about the systemic factors that allow biohacker spaces to flourish and support more inclusive innovation in the knowledge economy. In that context, we want to explore two aspects of the broader innovation system that will help us understand how biohacker spaces do, and might better, promote inclusive innovation. These two aspects are discussed in the following sections: i) regulatory and legal systems and ii) social and financial networks.

Flexible Regulatory and IP Systems

A crucial factor in supporting and sustaining biohacker spaces is a flexible regulatory regime. Laws of general application apply, of course, to biohacker spaces. But two areas of law, in particular, warrant special attention in this context: biosafety regulations and IP laws and policies.

Relaxed biosafety laws

Permissive biosafety regulations enable biohackers to work on audacious research projects. They allow biohackers to engage in more inclusive activities – from undertaking research to commercializing new products and processes to undertaking sophisticated projects to engage the community. However, a rigid and prohibitive regulatory system can have a chilling impact on the research potential of these spaces. Here, we discuss the benefits of a relaxed regulatory system to support inclusive innovation, and then we discuss a number of safeguards to mitigate legitimate biosafety and biosecurity concerns that arise from biohacking.

There is no doubt that biohacking poses biosafety and security risks. The practice may instill fear in the public. Hence, some people prefer a strong regulatory approach to do-it-yourself (DIY) biology. However, a tight regulatory system can be, paradoxically, more problematic for public safety. Although a citizen can easily set up a low-cost lab by ordering equipment and chemicals online, a strict regulatory system may drive biohacking activities underground, or at least behind closed doors, meaning that government is unaware of the dangerous activities that may be going on (Kellogg, 2012). A relaxed regulatory system, where biohacking can be closely monitored, is therefore actually safer and more transparent.

Looser regulations are also beneficial in promoting innovation. Regulations are precisely what limit the extent of research activities that biohackers can undertake. For example, an important difference between North American and European biohacker spaces is the distinct regulatory environments in which they operate (Seyfried et al., 2014). European biohackers face stricter regulations regarding the type of activities they can undertake. For example, European biohacker spaces must be licensed to carry out any genetic engineering experiments. Some community labs, such as La Paillasse in Paris, have successfully obtained a license. Several other labs are still in the process of becoming certified, which restricts the ability to innovate there. As Robert Carlson, a bioentrepreneur based in the United States, explains, "[T]he only thing we do if we restrict access to these technologies is slow ourselves down and incentivize other countries to go faster. We can't afford to unilaterally disarm." (Kellogg, 2012).

In Canada, most biohacker spaces operate at Biosafety Level 1, which means that they can work with biological agents, namely, Risk Group 1 agents, that are not known to cause disease in healthy humans (Government of Canada, 2015). Unlike in Europe, activities conducted at Biosafety Level 1 are not regulated in Canada, which enables greater research autonomy. Experiments involving Risk Group 1 agents in Canada are exempt from licensing requirements. As a result, the research activities of most DIY biologists are not directly controlled; biohackers are, however, advised to adopt "safe practices" to help mitigate harm (Government of Canada, 2016).

The DIY biology community has independently taken steps to address safety concerns associated with amateur work. For example, the DIYbio website (diybio.org) set up a question-and-answer feature on biosafety (Landrain, 2013), which allows members of the community to submit questions on biosafety such as how to safely clean up chemicals for a particular experiment. These questions are answered by professional experts including biosafety officers.

Local biohacker spaces have also taken proactive steps to address safety issues. For example, BUGSS (bugssonline.org), a biohacker space in Baltimore, has developed a chemical hygiene plan and a member safety training protocol that meets regulatory requirements (Scheifele & Burkett, 2016). It is also common for local spaces to develop their own safety training protocol (Scheifele & Burkett, 2016).

Other organizations also play a role in ensuring the safety of biohacker spaces. For example, a common public concern is that biohackers may take advantage of the existing system by building a dangerous pathogen in the lab. However, aside from the practical difficulties of actually working with pathogenic organisms, biohackers cannot simply order a pathogen's DNA (Maurer et al., 2009), not even in fragments. Member companies of the International Gene Synthesis Consortium (IGSC; genesynthesisconsortium.org) screen every DNA order against a database of sequences to determine if it includes pathogen DNA (Maurer et al., 2009). As a result of this process, successfully ordering pathogenic DNA is almost impossible. In addition to the measures biohacker spaces and associated organizations are adopting, biosafety risk is also mitigated through other safeguards built into the system. Even when biosafety regulations are relaxed, any new products that are created at biohacker spaces will have to go through necessary approval for commercialization. Depending on what product is developed, it may be subject to other national regulations before it can reach the marketplace.

The best way for government to address any biosafety concerns is by closely monitoring the biohacking movement through engagement and outreach. In the United States, the FBI has already started taking these steps (Wolinsky, 2016). They have been growing their presence in the DIY community and have successfully engaged it to openly talk about biosafety issues (Wolinsky, 2016). Canada is slowly catching up. In 2016, the Public Health Agency of Canada (PHAC; canada.ca/en/public-health.html) engaged with the DIY biology community by organizing a national summit to bring together key players who are part of the growing movement (Government of Canada, 2017). The PHAC also provides free online courses on biosafety as part of its efforts to create a culture of safety (Government of Canada, 2017).

To make biohacking more inclusive, it is important that biosafety is achieved through education and outreach rather than restrictive regulation. In the United States, the National Science Advisory Board for Biosecurity (NSABB; osp.od.nih.gov/biotechnology/nsabb-faq/) supports this view (Kellogg, 2012). Tighter regulations have the potential to impede meaningful and collaborative research as well as the level of inclusive activities these spaces can undertake. That is why continued engagement with the movement is key. Not only does engagement allow government to monitor risks, it also helps would-be regulators better understand how the movement is changing the science and innovation landscape before responding speculatively to potential problems.

Flexible IP systems

The recent CRISPR dispute – a fight over patents on technology that facilitates simple and low-cost genetic engineering – highlights some of the important implications of IP on accessibility of scientific research (Beck-Watt & Quainoo, 2016). Considered one of the biggest breakthrough technologies of the century, CRISPR allows scientists to make precise changes to specific strands of DNA at a more cost-efficient and faster rate than before (Ledford, 2016). A dispute arose between two feuding groups of scientists claiming patents over the gene editing technology (Beck-Watt & Quainoo, 2016). Despite the powerful nature of the technology, a patent dispute does little to advance science. Not only does it amount to large legal costs but it also demonstrates the inability of the patent system to match the speed of innovation (Feldman, 2016). Companies are still racing to develop applications of the technology and it is uncertain whether they will obtain a license for it, especially given that litigation is likely to be ongoing for the foreseeable future (Feldman, 2016).

Unlike conventional biotechnology research, users of biohacker spaces seem less interested in formal IP measures to appropriate their research, and more interested in open approaches to science. There is a strong tension between the open nature of biohacking and the closed nature of the formal IP system. We argue that a flexible IP system is important for supporting the inclusive outcomes arising from biohacker spaces.

Biohacking innovation happens using open science ideology, in the shadow of formal IP systems that are otherwise seen to be so crucial for biotechnology research. Research suggests that IP protection is more widely utilized by large companies, who consider IP rights important (Hall & Ham, 1999) in order to gain monopoly over an invention. Also, technologies such as pharmaceuticals and chemicals are highly patented (OECD, 2011). But, overall, only a small fraction of companies in all industries within high-income countries consider IP rights important (Jankowski, 2012).

Overuse of the IP system can impede biohacker spaces. IP rights create significant transactional and legal costs (de Beer, 2015). For example, the IP regime can be used to block biohackers from building on earlier inventions, which can potentially impede cumulative, sequential, or collaborative innovation (de Beer, 2015). IP rights can also impede inclusive innovation by restricting biohackers from undertaking projects aimed at achieving health, social, or environmental outcomes because of the transaction costs involved.

Furthermore, IP rights can constrain informal collaboration. One of the concerns reported by the Organisation for Economic Cooperation and Development (OECD, 2008) relates to the emergence of patent thickets, which describe overlapping IP rights (Shapiro, 2001). When IP rights are divided among various owners, it can result in a number of issues such as market delays, legal costs for accessing the technology, and dealing with owners who may not want to license the technology (de Beer, 2015; see also Schultz & Urban, 2012).

Biohacker spaces demonstrate that innovation can arise outside of the formal IP system in a way that embraces open science and inclusivity. As von Hippel (2005) explains, organizations that embrace user or collaborative innovation have different attitudes towards IP. He also argues that there are other ways researchers can realize the value of innovation besides appropriation from IP. For example, biohacker spaces increase opportunities for people to participate in research as a result of reduced costs and increase access to scientific outputs (in the form of data and publication), allowing subsequent innovation.

A number of projects have emerged from biohacker spaces in the shadow of the formal IP system. For example, a group of biohackers developed Open Trons (opentrons.com), an open source lab robot to automate lab work (Wohlsen, 2014). The project originated from Genspace and raised well over $100,000 on Kickstarter, meeting 125% of its fundraising goal (OpenTrons, 2015). Besides being a commercially successful campaign, the project also achieves other inclusive outcomes: it enhances understanding of lab automation through its open source technology and its low price compared to other lab automation robots enables access to this technology in labs that cannot afford the more expensive robots. In another example, a biohacker group in California is working to produce low cost open insulin, free of any patents (Di Franco et al., 2015; see also Ossolo, 2015), which can be significantly useful in improving access to health technologies.

For some innovators and their investors, there may be a role for IP to play at some stage in the commercialization process. However, marketplace framework policies should be developed in a way that support the innovative work emerging from these spaces (de Beer, 2015). Current IP laws and policies favour one model of innovation over another. As a result, those who wish to practice open innovation are forced to work within a system that supports closed innovation. We argue that policy-makers should offer equal support for those practicing user innovation, open innovation, and other forms of innovation as those practicing closed innovation. With more laws and policies that support open forms of innovation, biohackers will face fewer barriers to inclusive innovation.

Biohacker Spaces Rely on Networks for Funding and Collaborations

In this section, we discuss how biohacker spaces rely on both informal and formal networks to raise funding. Biohacker spaces raise funding differently from large-scale industrial science and technology institutions. They rely on alternative financing strategies, often driven by social networks, crowdsourcing, and communities of practice.

Funding models for biohacker spaces

One of the key challenges many biohacker spaces face is access to funding. Biohackers need basic funding to purchase equipment and materials. Unlike large-scale industrial science and technology institutions, biohacker spaces rely on alternative financing strategies to raise money.

The DIY approach for setting up a lab can be more cost-effective compared to conventional biotechnology. With the rapidly dropping cost for DNA synthesis and sequencing technology, biology is more accessible than it has ever been (Carlson, 2010). Using eBay, a molecular biology lab can be set up for a few thousand dollars containing the most basic tools (Kellogg, 2012). However, biological materials such as synthetic DNA sequences are still very expensive. In addition to the cost of tools, there may also be other costs in setting up a lab such as rent, utilities, and other start-up costs (Scheifele & Burkett, 2016). These costs for setting up a biohacker space are often not supported by traditional sources of funding.

Under the traditional research model, funding flows from government to researchers through public research grants or university operating budgets. Funding may also flow from venture capitalists to researchers to support industrial research projects. Those traditional forms of funding are typically not available to biohacker spaces because these spaces operate differently.

For instance, traditional biotechnology research at public research institutions in Canada is heavily supported by a federal research agency, the Natural Sciences and Engineering Research Council (NSERC; nserc-crsng.gc.ca). With an annual budget of $1.1 billion CAD, NSERC is the largest source of funds for science and engineering research in Canada (NSERC, 2017). It funds a range of awards from graduate scholarships to post-doctoral fellowships to fund research tools and infrastructure. However, community labs are largely ineligible for these research funds. Because community labs are typically independently run, they may not qualify for federal research funding, which is primarily targeted at post-secondary institutions.

In addition to federal research funding, venture capital (VC) is another source of funding available, particularly for commercial research. Venture capitalists provide early-stage financing to companies in return for an equity stake (OECD, 2015). The acquisition of IP rights can signal commercial potential to venture capitalists (OECD, 2015). However, since VCs are interested in scalable projects with a high potential for growth, this form of financing may not be available to help finance local, small-scale biohacker spaces.

With limited access to capital, community labs are looking to alternate ways to fundraise. The new inclusive innovation model emerging in biohacking shows that funding can be acquired organically, through grassroots networks. More inclusive funding supports a greater diversity of people who undertake biology projects.

In particular, biohackers are looking to crowdfunding as an alternative to conventional VC. Crowdfunding allows anyone with an idea seeking capital to implement their idea through the use of a crowdfunding platform (Thring, 2012), and it typically involves distinct IP management strategies (de Beer et al., 2017b). Kickstarter, Indiegogo, and Kiva are some examples of the most popular crowdfunding platforms. Unlike traditional research grants, which impose many requirements and qualifications for funding eligibility (NSERC, 2017), crowdfunding is open to anyone with an idea, with minimal requirements. The success of the campaign largely depends on the merits of the idea and the campaign marketing.

Several labs such as Biocurious in the United States have used crowdfunding to set up their labs. Biocurious successfully raised $35,000 USD through its campaign, helping fund equipment, tools, reagents, and its rent at a local facility for the first few months (Network for Open Scientific Innovation, 2011). Compared to research labs at universities and industries, which may cost hundreds of thousands to finance (Hoag, 2015),

$35,000 is comparatively cheaper and goes a long way in supporting access to tools to a wide range of community members.

Besides crowdfunding, practically most of the activities at the community labs are self-funded through membership and workshop fees (Landrain et al., 2013). The labs may also rely on private donations to raise money.

The combination of biohacking and crowdfunding demonstrates that future research projects can circumvent traditional funding sources and support more inclusive groups to undertake research projects. Anyone with a biotechnology idea can look to crowdfunding to raise capital for their research project. Considering how provident the managers of many biohacker spaces are, the availability of more research funding for these spaces can make a huge impact in supporting entrepreneurship and innovation outside of academic and industrial walls.

Collaboration with formal institutions and informal networks

The communities of people who use biohacker spaces tend to highly value the ability to conduct their work outside of academic and industrial walls, but they also value collaborations. They collaborate not just with formal actors in the traditional commercial innovation system but with informal actors as well, supporting more inclusivity.

Under the traditional biology research model, technology transfer allows universities and industries to diffuse technology from its place of origin to more people and places (Mansfield, 1975). The transfer can occur among universities, from university to industry, from government to industry, as well as between smaller companies and larger companies (Mansfield, 1975). It can occur horizontally or vertically depending on whether the technology moves from its application in one place to another or whether the process moves from basic to applied research or development (Mansfield, 1975). Our discussion here focuses on vertical technology transfer, where knowledge, skills, resources and technologies are shared in a way that ensures further development of technology into new products and services that are accessible to a wide range of people.

Many universities and industries have a formally designated office of technology transfer that identifies university-originated research with commercial potential (Santos, 2010). These offices play an important role in finding strategies to commercially exploit research, which may occur through licensing agreements with other industry partners to help bring technology to market (Santos, 2010). The rise of technology transfer in universities was largely influenced by the United States Bayh–Dole Act of 1980, which caused a major shift in academic entrepreneurship (Sampat, 2006). By allowing recipients of public funding to obtain IP rights on the outcomes of research, Bayh–Dole provides incentives to universities for commercially exploiting research. As a result, universities have become more interested in acquiring IP rights and value academic entrepreneurship (Popp, 2008).

In biotechnology companies, technology transfer can take place internally and externally. Particularly in large companies, technology transfer takes place internally from the research and development (R&D) team to the manufacturing team to help commercialize the technology (Mansfield, 1975). Technology transfer can also take place from one company to another to outsource manufacturing activities (Mansfield, 1975). Many companies will conduct their own R&D but lack infrastructure to commercially develop the technology. For instance, some companies may lack the resources to conduct clinical studies for the drug product. Transferring the technology to another company may help scale up the product and produce it faster and cheaper than in-house production.

Biohacker spaces tend to operate differently than academic and industry institutions. Biohacker spaces tend to rely on both formal and informal networks to support research and commercialization. Within formal networks, biohacker spaces value collaborations with government, universities, as well as industrial partners. Such collaborations allow biohackers to access financial support, equipment, and other resources. The collaborators may also benefit from the exchange as it presents an opportunity to harness innovative ideas emerging from the biohacking movement (Buys & Bursnall, 2007).

Many spaces organize meet-ups and events to bring together diverse members of the community. These events not only help attract new members but also help encourage informal collaborations through knowledge exchange and skills transfer. They allow diverse interests and people from a range of disciples, age groups, and skill expertise to come together to achieve a common goal through interaction, information gathering, and coordinating research activities (Jassawalla & Sashittal, 2007).

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By bringing the DIY biology ethos into the collaboration, biohacker spaces encourage ideas and resources to be shared. Through grassroots entrepreneurialism consisting of formal and informal collaborations, these spaces encourage inclusivity and have the potential to identify and exploit innovative ideas even with the limited resources they have. Together, this can help break down barriers between researchers and partners to create knowledge clusters that can "eliminate bottlenecks imposed by upstream research" (Gold, 2016).

Conclusion

Exploring biohacker spaces through a framework of inclusive innovation facilitates analysis of details related to four dimensions of inclusivity. By considering issues around biohacker spaces related to people, activities, outcomes, and governance, we have demonstrated one way to categorize and analyze the highly variable nature of these spaces. We find that biohacker spaces are contributing to a new innovation paradigm for biotechnology, outside of the traditional confines of – and more inclusive than – the triple-helix university–industry–government innovation system.

We have further added to the inclusive innovation analytical framework by introducing two sets of considerations related to innovation ecosystems that can make biohacker spaces more or less inclusive. Our research shows how biohacker spaces benefit from flexible IP policies, a relaxed regulatory framework, decentralized funding opportunities, and strong partnerships with formal and informal networks. Those who are researching, managing, or interested in supporting biohacker spaces can promote more inclusive innovation by focusing attention on the systemic factors we have identified.

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