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The rise of biohacking: Tracing the emergence and evolution of DIY biology through online discussions

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ABSTRACT

This article traces the rise and evolution of do-it-yourself biology, also known as biohacking, by analysing its main discussion forum, launched in 2008. Our methods combine three tools (Extractify, L@me, and iRaMuTeQ), a quantitative data analysis, and qualitative content analysis. Our analysis shows that the forum serves as a nexus for a variety of concerns: discuss science and technology, organise meetings, create groups, make announcements, reflect on issues such as ethics, law and regulation. Despite this heterogeneity, most discussions concern knowledge and equipment: one of the main functions of the forum is finding, sharing, documenting and developing techniques and protocols to do DIY biology. Our analysis further shows that in its beginnings, the forum was centered on one single city and that organisational matters were prominent in discussions. But with the rise of laboratories and local groups dedicated to DIY biology, the flow and content of communication has evolved. We identify a key turning point in the years 2013/2014, marked by a regional and economic structuration of the movement and a decrease in the overall traffic on the forum. We thus argue that the emergence of DIY biology has known two distinct phases: a phase of constitution (2008–2012) and a phase of maturation and autonomisation (from 2013 onwards). While the first phase is marked by the local dimensions of people's engagement and by exchanges of knowledge and methods, the second phase is marked by more strategic efforts to sustain and institutionalize the community and by a more reflexive stance concerning its autonomy and positionality.

[1]This article belongs to the special section on Do-it-Yourself Laboratories (DiY Labs): Implication for Science, Technology, and Innovation (STI) Policy.

1. Introduction

The aim of do-it-yourself (DIY) biology, also called “biohacking”, is to make biology accessible to non-scientists. Over the past decade, DIY biology has evolved from a small and local initiative to a transnational movement. In early 2008, the movement was in its beginnings. A discussion forum was launched in early April 2008 (which included 32 members in April). One month later, about 25 people got together for their first meeting in a pub in Boston (Bobe, 2008). Today, the discussion forum counts over 5000 members and many events have been held, and community spaces been created, across the world. According to the main website dedicated to the movement (diybio.org) there are currently over 100 groups interested in DIY biology across the world, most of which are located in Europe and in the United States. Roughly half of these groups have their own physical spaces, be it in places like Amsterdam, Lima, Paris, or New York. DIY biology has even been featured in documentaries (i.e. Schlichter and Karberg, 2012; Lassale, 2019), in exhibitions (at the Science Gallery in Dublin, the Medical Museion in Copenhagen, the Science Museum in London, and Ars Electronica in Linz), and in TEDx talks.

Bios

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In this article, we analyse the rise and the evolution of DIY biology via online discussions. While academic texts have described the beginnings of the movement (i.e. Delfanti, 2013; Tocchetti, 2014), none have examined in detail the movement's constitution, and only a few articles have touched upon its evolution and transformations (including Delfanti, 2014; Meyer and Wilbanks, 2020). And while academic work on DIY biology has mobilised qualitative methods (interviews, observations, document analysis), there is hardly any article that relies on quantitative methods. There are, according to our knowledge, only two texts that mobilise quantitative methods: a survey by the Woodrow Wilson International Center for Scholars (2013) and the Masters' thesis by Schulz (2014), which includes a small survey.

Our article aims to contribute to the literature on DIY biology and, more generally, to the theme of this special issue - the rise of DIY laboratories - in two ways. First, it offers a quantitative analysis of the movement by analysing the main discussion forum dedicated to DIY biology. It examines the kinds of issues discussed, the issues that attract most comments, and how the communicational flow and content of the forum has evolved. To be able to analyse our corpus of data (about 6000 topics and 40,000 messages) we had to develop and bring together different tools to carry out a variety of tasks, from scraping and cleaning data to producing statistics and multidimensional analyses. Our article presents the first analysis of its kind of DIY biology. A second contribution is that the paper discusses empirical data over a period of 12 years. Most existing literature on DIY biology can be regarded as "presenteist" in that it usually provides an analysis of the movement's practices, ethics, organisation and/or politics at the time of the inquiry. Our paper, in contrast, looks at DIY biology over a longer period of time, by empirically tracing its beginnings and the changes and reconfigurations over the years. The paper is structured as follows. In the next section (Section 2) we discuss the history, practices and politics of DIY biology. We then explain our questions and the methods we used (Section 3). Thereafter, we present and discuss the main results (Section 4).

2. DIY biology: history, practices and politics

Even before 2008, terms such as "garage biology" and "DIY biology" began to circulate. In 2005, for instance, biologist Rob Carlson (2005) predicted that "The advent of garage biology is at hand. Skills and technology are proliferating, and the synthesis and manipulation of genomes are no longer confined to ivory towers". In 2006, biologist and computer scientist Attila Chsordash (2006) wrote about "the coming world of personal biotech", signifying that the "beautiful retro idea of tinkering with digital devices in a garage […] can be extended to biotech too"; he also used the term "bioDIY." 2008 is usually taken as the date of birth of DIY biology. Mac Cowell and Jason Bobe - both owning Bachelor degrees in biology - launched DIYbio (both the website and the discussion forum) in order to create a "focal point" for "amateur biology" (Nair, 2009).

But despite the recent history of DIY biology, its genealogy needs to be traced back in connection to various other developments within – but also outside of – science. First, as the term biohacking suggests, there is a close connection between biohacking and hacking. The connection is not only semantic but also ethical and philosophical: ideals such as openness, access, sharing, and decentralization are key principles in both fields. There is also a spatial proximity between these areas of practice. Numerous activities and groups did start off within already existing hacker labs. For example, in 2011 several DIY biology projects were launched at the MadLab in Manchester (created in 2008 - see Bell et al., 2014) and there are numerous accounts of people, such as Berlin resident Lisa Thalheim, who moved from computer hacking to biohacking (see Charisius et al., 2013). DIY biology is embedded within the larger peer production and open source movements which mainly developed from the 1990s onwards. DIY biology is not the only field that has roots in hacking and open source movements: open source agriculture, open source ecology, and open source architecture are other examples. The rise of DIY biology is also closely connected to the maker movement and the magazine MAKE which have provided a "hospitable" forum (Tocchetti, 2014, p. 136). The maker movement, in turn, can be linked to the do-it-yourself tradition, that developed from the 1950s and 1960s onwards (including dedicated magazines, books, shops and TV shows).

Apart from these links to hacking, making and open source, there is also an important connection between DIY biology and synthetic biology. The vision promulgated by synthetic biology – that engineering principles can be applied to biology in order to create new substances or organisms – has been influential. Numerous founders of DIY biology laboratories have met at the international Genetically Engineered Machine (iGEM) competition for students in synthetic biology. Some of the key features of the iGEM competition – a mix between entrepreneurial spirit, fun, team-work, reflections on ethical and social issues, and a positive attitude towards science – can also be found in DIY biology laboratories. However, until 2013, DIY biology laboratories were excluded from the competition – issues of security, responsibility and governance were put forward as the reasons. It wasn't until 2014 that a "community labs" track was opened at the competition in order to welcome projects from community laboratories. Finally, the rise of DIY biology can be placed within the longer history of the contribution of amateurs and citizens to science - examples being popular epidemiology (Brown, 1992), AIDS treatment activists (Epstein, 1995), patient groups of rare diseases (Callon et al., 2001), natural history (Alberti, 2001), and plant breeding (Curry, 2014).

Who are the people doing DIY biology? According to a survey carried out in 2013 by the Woodrow Wilson International center for Scholars ($N = 359$), DIY biologists work on average 7 h per week on their projects, they are well-educated, more than half of them are fully employed (besides their DIY biology activities) and 25% are students. About two thirds are between 25 and 45 years old and three quarters are male.[1] Trojok (2016, p. 155) states that within the movement we find natural scientists, engineers, artists, philosophers, most of which have university degrees. In a similar vein, Charisius et al. (2013, 23) declare that the movement comprises nerds, entrepreneurs, hackers, professional scientists, etc.

The diversity of people interested in DIY science has also generated a large diversity of activities: extracting DNA for genetic testing, producing bioreactors, creating fermentation kits (i.e. for homebrewing), doing bio-art projects, developing biosensors (i.e. to detect the presence of contaminants in the environment or in food), giving lectures and organizing workshops, and fabricating cheaper alternatives to scientific equipment. Five main families of activities can be distinguished within the DIY biology movement:

- The development of low-cost equipment,
- Projects concerned with the environment and health issues
- Bio-art projects
- Educational and outreach activities such as workshops, introductory courses, conferences and classes
- Entrepreneurial projects, creation of start-ups

There are certain differences in the kinds of projects done in Europe in comparison to the US: in Europe there are stronger collaborations between DIY biologists, artists, and designers than there are in the US (Seyfried et al., 2014), and regulation is less strict in the US (where it easy to produce GMOs in a DIY biology laboratory) than in Europe (where it is very difficult to get an authorization to produce GMOs

[1] A smaller survey ($N = 48$), carried out at two biohacker events in Amsterdam and in Berlin, yielded very similar events: 69% are male, 60% are between 25 and 40 years of age, and most of them have academic degrees (Schulz, 2016, pp. 67-75).

outside scientific institutions). Despite this heterogeneity in terms of practitioners, projects and interests, there are some elements that are relatively widely shared. Openness, accessibility, transparency, responsibility: these are some of the terms commonly used by DIY biologists. The key argument put forward is that the life sciences (including molecular biology, genetics, but also medicine) should not be activities only carried out by professional researchers in their "ivory towers", but, instead, other actors should also be involved too (be they called "people", "citizens", "amateurs", etc.). The argument, simply put, is to *democratize* science. This democratization is a process that is at once spatial (construction of new spaces), technical (creative workarounds around equipment), social (establishment of accessible networks/laboratories) and political (calling for a citizen science and criticising traditional institutions) (Meyer, 2013).

But this democratisation has also led to concerns about security, safety and regulation. Especially in the early days of DIY biology, a number of media articles portrayed the movement in negative terms, and pondered on the potential threat of bioterrorism (Anonymous, 2010; Whalen, 2009). There have been different kinds of responses from the DIY biology community to such safety and security concerns: collectively establishing a code of ethics in 2011 (with principles such as "emphasize transparency," "adopt safe practices," "promote citizen science and decentralized access to biotechnology") (see e.g. Eggleson, 2014); setting up a portal in 2013 through which people can ask questions about safety to a panel of biosafety experts. The fact that, as a consequence of safety and security concerns, DIY biologists have even been in touch with the FBI has been discussed in numerous texts (Charisius et al., 2013; Ledford, 2010; Meyer, 2015b; Tocchetti and Aguiton, 2015; Wolinski, 2016).

Academic work on DIY biology has so far mainly focused on six related themes: its historical antecedents (Curry, 2014; Kelty, 2010; Tocchetti, 2014), its materiality (Delgado, 2013; Meyer, 2013, 2015a), identity (Esquivel-Sada, 2017; Meyer, 2016), ethics (Bagnolini, 2018; Eggleson, 2014; Keulartz and van den Belt, 2016), politics (Delfanti, 2013), and economics (Delfanti and Söderberg, 2018; Meyer and Wilbanks, 2020). The issues of the democratization of biology, as well as the links between hacking/open source, biohacking and synthetic biology, have been addressed in most academic texts. Our article aims to contribute to this growing academic literature (see Fig. 1) by focusing on the making and the evolution of the movement from the vantage point of a dedicated discussion forum.

3. Questions and methods

3.1. Research questions

Our initial question was this one: What kinds of information do commentators share on the DIYbio forum? While such a question might look banal, we hold that this is far from being just a secondary question in the making of the DIY biology movement. Instead, following discussions on the forum is an excellent vantage point from which to examine how DIY biology is made: the forum provides a means for people to exchange knowledge, tools, and interests and a way for coordinating concrete actions. The DIYbio forum is a place where communication happens in a very open, direct, and rather uncensored way, providing a relatively genuine view of the inside dynamics and practices of the movement. Given that the rise of DIY biology cannot be evaluated by scientometrics or by examining the creation of academic departments, journals, etc. (the methods that scholars interested in the rise of an academic discipline might use) the DIYbio forum is perhaps one of the only places to capture the dynamics of DIY biology as a whole. According to one of the co-founders of *Genspace* in New York, "the founding of the DIYbio Google Group by Mackenzie Cowell and Jason Bobe [...] was the key step in establishing the DIYbio movement" (Jorgensen, 2014). Since the main aims of DIY biology are described in terms of a "democratisation" and "opening up" of biology, a discussion forum is arguably a worthwhile site to explore these dynamics. This led us to reformulate our initial question as follows: How is DIY biology made and how is it made shareable through the DIYbio discussion forum? How can we trace the emergence, the making and the evolution of the DIY biology movement through the forum? We hold that these research questions are important to ask because the academic literature does not provide empirical insights into the DIYbio discussion forum and since the forum constitutes a rich and unique source that allows us to examine the dynamics and trajectories of the DIY biology movement over time.

In order to further unpack this question and to be able to operationalise it methodologically we posed to the following sub-questions:

- Q1: What is the content of the first comments on the forum?
- Q2: Overall, what types of topics are posted and which kinds of issues are discussed on the forum?
- Q3: What kinds of topics attract most replies and most views?
- Q4: How has the forum and its content evolved between 2008 and 2019?

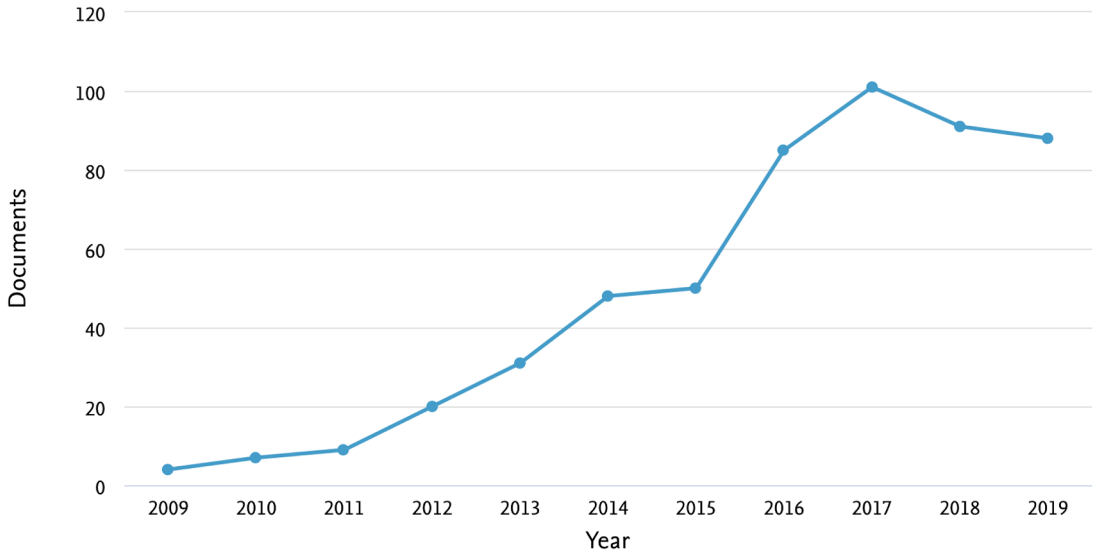


Fig. 1. Number of academic articles containing the keywords "DIYbio" or "DIY biology" or "biohack*" since 2009 (Source: Scopus).

We decided to pose these four sub-questions in order to be able to capture at once the beginnings, the content, and the evolution of the forum. Based on these questions, we formulated four hypotheses:

H1. The first comments on the forum render explicit the key aims and objectives of DIY biology and provide evidence of the material constitution of the movement.

H2. Contributors discuss a range of issues, ranging from technical issues to social and political issues.

H3. Contributors are more interested in "actionable" knowledge, such as discussions about alternative tools and protocols, than "passive" knowledge, such as announcements of articles, conferences, etc.

H4. The forum and the content of the discussions has evolved since the beginnings of the DIY biology movement, revealing a professionalisation and structuration of the movement.

While H1 will be tested by a qualitative content analysis, H2 to H4 require a mix of qualitative and quantitative methods (statistical analysis of word occurrences, of numbers of subjects and messages, etc.).

3.2. Methods

We used various methods and sources for our paper.[2] We first of all searched the main websites of the movement - https://diybio.org and https://sphere.diybio.org - for relevant data. We found two relevant lists for our research questions on https://sphere.diybio.org: a list with DIY biology labs, and a list with start-ups. We used both lists in order to represent and examine the evolution of labs and start-ups from 2008 to 2019.

Apart from these sources, the empirical heart of our paper consists in an analysis of a forum: the main discussion forum of DIY biology, hosted on the free online service Google Groups. Google Groups allows their users to participate and read discussions by email: each participant can send and receive the messages of the discussion on their mail account. Google Groups are self-organised groups which provide relative freedom and simplicity for its users (Prescott, 2010), and while they can foster peer engagements and academic networking, problems such as asymmetries in participation and dominance of some groups/persons can arise (Rambe, 2017). The DIYbio Google Group can be defined, following Porter (2004), as an "member-initiated" virtual community that serves to foster "social" relationships among members. The DIYbio Google Group currently has 5068 members. The first message was posted on the 5th of April 2008 by Jason Bobe, the owner of the forum. At the moment of writing (June 2020), 6261 topics have been posted. While the forum is public and everyone can read the comments, only members can post comments and access the list of members.

We have analysed a selection of comments qualitatively. We have, in particular, read and analysed all the comments posted on the forum during April and May 2008 (hypothesis 1) and read those topics which have attracted a particular high number of comments (>55) or views (>1000). We also searched for, selected and read those topics directly concerned with the DIYbio forum and community itself, such as *How big is the DIYBio community?* (2-22/3/2017, 9 comments, 98 views).[3] And when faced with a significant issue identified by our quantitative methods, such as a decrease in overall communication, we searched for and read comments that could provide possible answers, such as the topic *Why aren't DIYbio events being posted here? Regional DIYbio lists splinter the community* (8-16/2/2013, 6 comments, 49 views). It is important to note therefore, that despite the rather linear discussion of our methods in this section, we needed to move back and forth between a qualitative analysis and a quantitative analysis in our research - as Akrich (2019) did in her analysis of a discussion forum on health issues.

To perform a quantitative analysis of the forum we had to use various tools and we had to surmount a number of hurdles. First, the scraping of the forum was made via the program Extractify (Vergnaud, 2020a). Extractify is an extension for Chrome, developed in JavaScript under Bracket, whose purpose is to scrap structured data on the web. It has been designed for collecting online comments or online conversations such as forums. Unfortunately, we could not access the whole corpus of messages on the forum via email, because users only receive messages from the date of their registration onwards. The tools that we had at our disposal for formatting and analysing the messages were therefore ineffective. The only way to access all messages was via the web page of the list (https://groups.google.com/forum/?fromgroups#!forum/diybio). While this page is freely accessible, and we could thus use Extractify, the web page's structure made it difficult for us to perform an automatic data extraction. The first difficulty we encountered is located on the main presentation page of the topics.

As can be seen on the screenshot above (Fig. 2), the page does not immediately load all the messages, because the page's script adapts them to the screen size (i.e. on a laptop with a 13-inch screen, the last 30 messages of the list will be loaded; on a desktop computer with a 27-inch screen, there will be 60 messages). To obtain a visualization of all the messages, the user has therefore to scroll down the page in order to tell the interface to load the following 30 messages, and so on. Thus, in order to see the more than 6000 topics for our study, more than 200 "scrolls" need to be done. Extractify had originally been designed to perform scrapping operations in a new tab in order to keep intact the elements viewed and selected by the user. We thus had to develop a new function which could do the contrary: extract what is visible in real time (in our case: the page containing all the topics of the discussion list after scrolling down). Once this pitfall was dealt with, we faced another problem: unlike the page presenting the topics, the pages with messages do load all the messages, but not their entire content, as can be seen on the following screenshot (Fig. 3).

To be able to read all the messages that do not open up (first red frame), the user must click on each message (second red frame) - a procedure that we had to mimic computationally.

The second step was to import our corpus into the program L@ME (Vergnaud, 2020b) to provide first statistics. L@ME is a software for processing and analyzing electronic messages, developed in JAVA under Eclipse. It allows its user to: open locally electronic messages or download messages located on a PhpBB forum or import messages from an Extractify json file; view and obtain data for each message, author and discussion; group discussions according to several parameters; clean up authors and topics of messages; split and merge lists according to different parameters; obtain general statistics on the list (i.e. number of speakers, of subjects, of messages), statistics on the dominant speakers of the list, as well as statistics on the collective subjects. L@ME allowed us to examine the kinds of issues discussed and the kinds of

[2] None of the authors have been directly involved in DIY biology activities. The first author has analysed the movement since 2012, and the second author since 2019.

[3] Here is the full list of the topics that we selected: "How big is the DIYBio community? #OPENBIOTECH vlog series", "Announcing DIYbiosphere – connecting DIYbio activities worldwide", "communities of DIYbio", "global DIY Biology Survey", "Biohacking in the world society", "community lab", "List of DIY Bio spaces", "Wikipedia clean up", "Why aren't DIYbio events being posted here? Regional DIYbio lists splinter the community", "Goals of DIY Bio", ""Official" DIYbio community survey - part of Statistical Studies of Peer Production is on!", "Return of the FAQ", "Who makes up DIYbio and what are our goals?", "DIYbio Community magazine?", "census of DIYbio spaces", "should we facebookize our group?", "Created a new diybio google group for those who simply want to post without being harassed by formatting nazis", "List Standards", "DIYbio FAQ v1 needs your help"; "Mailing list woes and a possible solution", "I just created DIYbio forums", "This Week in DIYbio + Reducing list traffic", "DIYbio Collaborative List Curation".

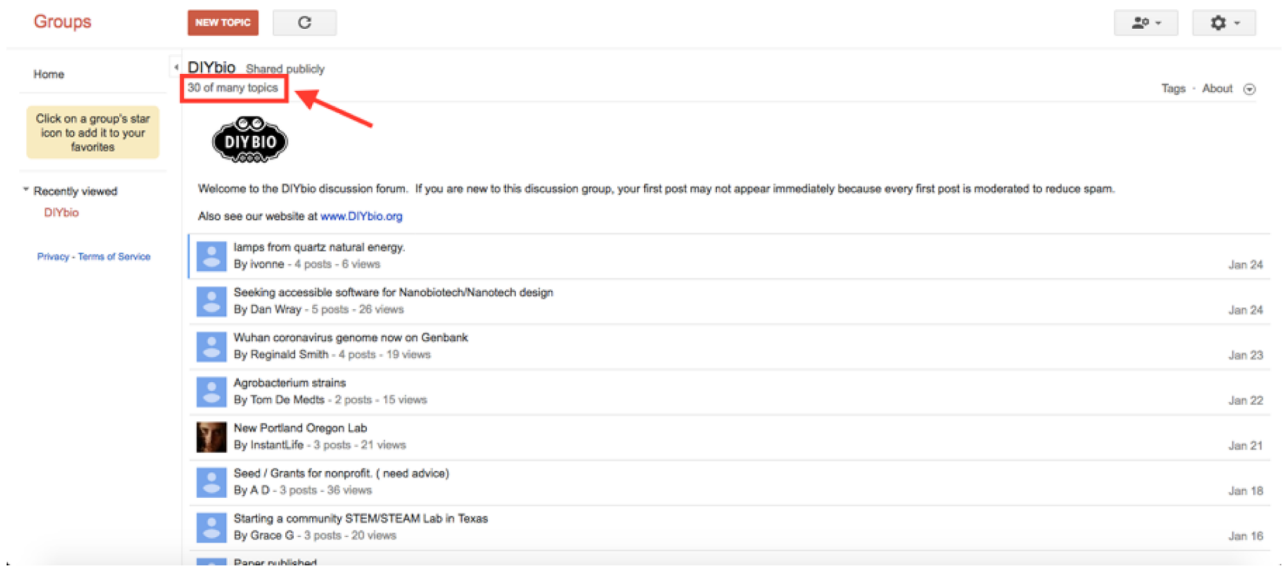


Fig. 2. Screenshot of the main web page of the DIYbio discussion forum.

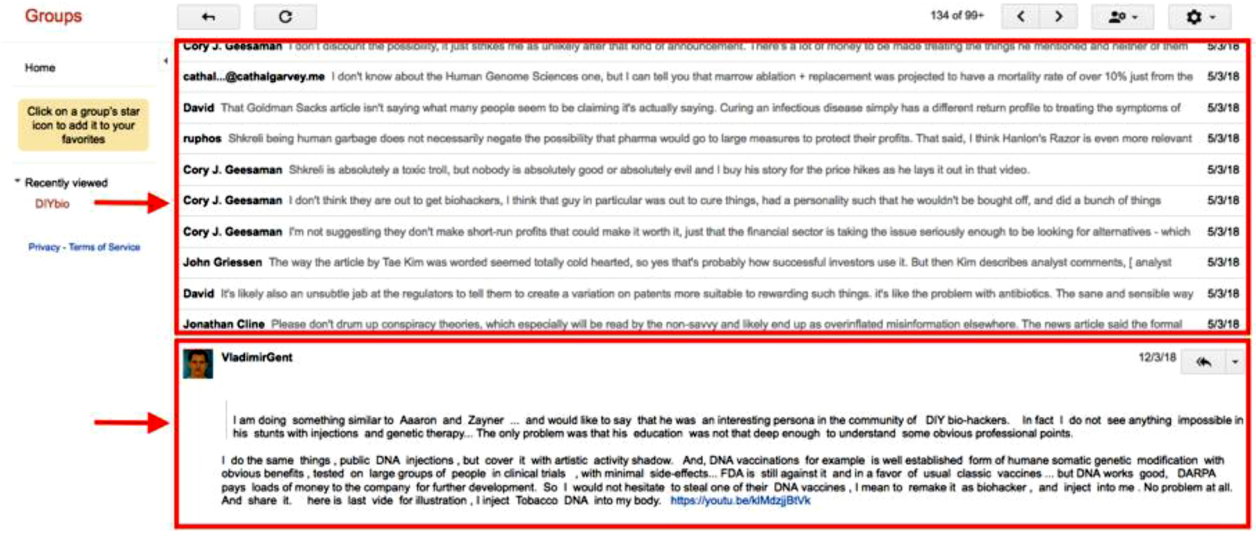


Fig. 3. Screenshot of a topic on the DIYbio discussion forum.

knowledge most valued on the forum - and thus to test our hypotheses 2 and 3.

Third, we used iRaMuTeQ, a program for the multidimensional and statistical analysis of a corpus of text (Ratinaud, 2020). iRaMuTeQ is based on the Max Reinert classification method (Reinert, 1983, 1986, 1990), an analysis which is based on a hierarchical descending classification. While iRaMuTeQ offers three classification methods, we chose the double classification method based on the groupings of text segments, in particular to test hypothesis 4. To examine if and how the content of the discussions has evolved, we carried out, for each individual year, a classification analysis of the topics posted to the forum (see Appendix D).

In hindsight, we realised that our methods mirror to some extent our research object: as much as DIY biologists are interested in accessible and affordable technologies, we also wanted to use accessible and affordable methods for our analysis. And as much as DIY biologists follow an ethics of open source, the three programs that we used for our analysis - Extractify, L@me, and iRaMuTeQ - are all open source.

4. Results and discussion

To assess the rise of DIY biology we examined, first of all, when and how many community laboratories have been created. The platform https://sphere.diybio.org provides a list of laboratories, including their names, location and (in most cases) their date of creation (see appendix B for a complete list and for other sources we consulted). Fig. 4 represents the evolution of the number of laboratories between 2008 and 2019.

Three phases can be observed: the beginnings of the movement, during which the first laboratories were created (2008–2012), a period of rapid growth during which around 10 laboratories are created each year (2013–2015), and phase of relative stabilisation from 2015 onwards. While the number of DIY biology laboratories is relatively easy to assess, the number of DIY biologists is far more difficult to estimate. The survey by the Woodrow Wilson International Center for Scholars (2013) had 359 respondents and in the topic *How big is the DIYBio community?* (2017) several figures are given: “globally [...] something like 2000″, “5000 people in Europe”. Apart from these figures, the geographical spread of the movement also needs to be

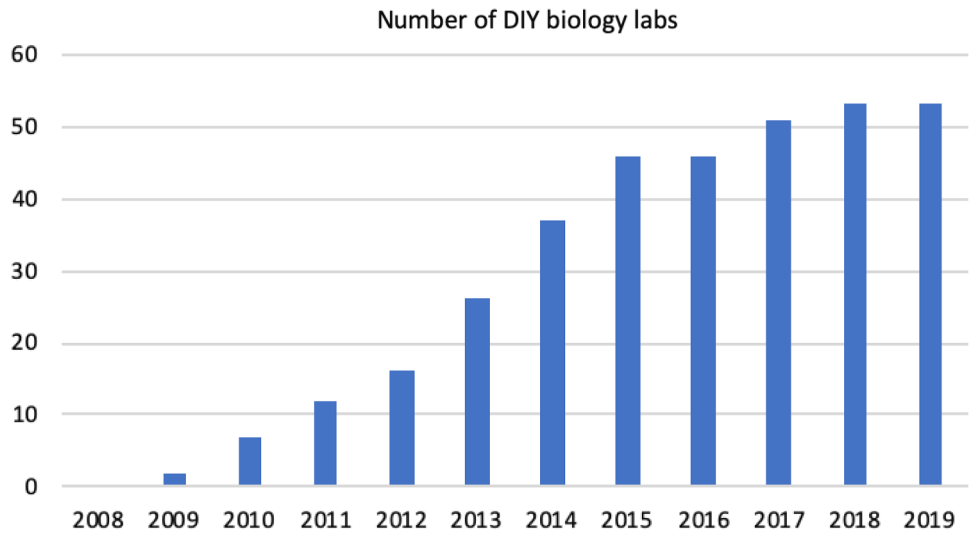


Fig. 4. number of DIY biology laboratories (source of data: https://sphere.diybio.org and various other sources, see Appendix B).

highlighted: out of the 53 laboratories that exist today, 23 are located in Europe and 20 in the USA. Most laboratories are located in big cities, and many in the capitals of their respective countries (Amsterdam, Bangkok, Berlin, Copenhagen, London, Lima, Ottawa, Paris, Prague, Stockholm, Vienna).[4] There has undoubtedly been a "rise" of DIY biology, even if it is important to note that this rise is not evenly spread across the world, but concentrated in the West and in rather large cities.

We then analysed a second relevant list on the platform https://sphere.diybio.org which lists the start-ups that have been created. Fig. 5 represents the evolution of the number of startups between 2008 and 2019. Three phases are visible: the first initiatives (2012–2013), a rapid growth from 12 to 24 startups (2014–2016), and a relative stabilisation from 2016/2017 onwards, with 30 start-ups today. In comparison to the rise of laboratories (Fig. 4), the rapid growth and the stabilisation happen over a similar period (roughly one year later). A key difference is of geographic nature: the creation of start-ups is more developed in the US (18) than in Europe (9), and much rarer anywhere else in the world (3).

Let us provide some more details of one of these start-ups, called Bento Labs, which sells a portable DNA laboratory (including a thermocycler, a centrifuge, a gel box, and a transilluminator). Its history can be summarised as follows: the first prototype is presented at the iGEM competition in 2013, the company is created in 2014, a (successful) crowdfunding campaign is launched on the platform KickStarter in 2016, and the company starts shipping their products in 2018 (Boing, 2019). According to biologist Sleator (2016, p. 712), Bento Lab illustrates the "ingenuity" of DIY biology and "the inventiveness of its practitioners in leveraging alternative funding mechanisms that exist outside the restrictive confines of traditional, university centric, research funding instruments". But the story of Bento Lab is interesting for two additional reasons. On the one hand, it illustrates the links between DIY biology and the iGEM competition. On the other, it reveals the potential time gap between the creation of a company and the selling of a product: an interesting question for further research - but which lies beyond the scope of this paper - would be to examine in more detail the rise of market products dedicated to DIY practices.

4.1. The content of the first posts

In order to better understand and situate the beginnings of the DIY biology movement, we examined the first comments posted on the forum. The very first posts are concerned with establishing a community of DIY biology in the city of Boston.[5] In his first comment to the forum, one of the two co-founders explains: "Boston may be able to contribute [...] toward the development of a thoughtful DIY bio-explorer / bio-hacker community. [...] Lets seize the moment!" (5/4/2008). While the second comment is from a person in Palo Alto signalling his interest, the third and fourth topics deal with the question of equipment and protocols:

> "We need to start aggregating a list of wetlab tools and techniques that might be practical to use in a garage or kitchen - stuff like the $15 PCR machine and substituting jello for agar, or building a centrifuge from an old dryer, etc." (6/4/2008)

> "The first couple of meetings of the group will likely focus on identifying research techniques that might be practical in a homebrew lab and identifying the main stumbling blocks [...] I would guess the main problems will be 1) acquiring or building the necessary lab equipment, 2) figuring out what to work on, and 3) figuring out how to actually do the work, i.e. adapting the existing wetlab protocols to work in a homebrew environment." (6/4/2008)

These comments, as well as several subsequent comments posted during April and May 2008 are about the tools, techniques, and equipments for doing DIY biology. Out of the 33 topics posted, 8 address technical issues. A key objective of the emerging DIY biology movement can thus be summarised as follows: finding, sharing, documenting and developing techniques and protocols to do DIY biology.

The biggest discussion during April and May 2008 (27 comments) concern a practical matter: the number of persons to attend the first meetup of the community. To the injunction "Please RSVP for the May 1st event at Asgard's in Cambridge by responding to this email" people responded along the lines of "I'm in", leading to a list of 20 people at the end of the topic. Overall, 8 topics address organisational issues (i.e. meeting up, collaborative list curation, communication) over the first two months of the forum.

The first meetup of the community, which took place on the 1st of

[4] It shouldn't come as a surprise that the geographical scope of academic work has been mostly limited to either the US or the European context. Kera (2012, 2014, 2015) is among the few scholars to have looked into Asia and the Global South as other sites of DIY biology.

[5] While the first posts are specifically concerned with Boston, there are already messages in April 2008 from people from other places (i.e. Paolo Alto, Belmont, Seattle) signalling their interest.

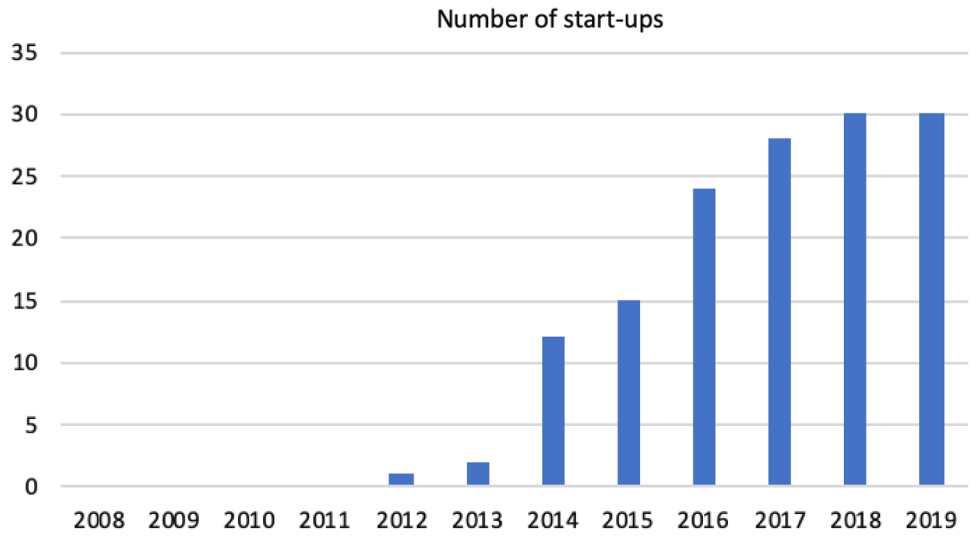


Fig. 5. number of startups connected to the DIY biology movement (source of data: https://sphere.diybio.org, see Appendix C).

May in a pub, was advertised as follows:

> "DIYbio is a nascent community of biological engineers that fosters the values of openness & responsibility and shares educational resources & techniques for do-it-yourself biological research and engineering. Tomorrow, with your help, we will draft a provisional DIYbio manifesto that will shape the long term vision of the organization and the attitude of the community. Provisionally, we want to foster a constructive society of citizen scientists and build "the Institution for the Amateur" - an umbrella organization that provides some of the same resources afforded by more traditional institutions like academia and industry - resources such as access to a community of experts, to technical literature, to responsible oversight for health and safety, and an official interface between the community and the public at large. In addition to forming the long term direction of the group, we will present and collect a list of existing experimental resources for biological research and engineering, and brainstorm one or two collective experiments we as a community could accomplish in the first year. We hope to see you at the discussion tomorrow evening. Let's build the future together." (30/4/2008)

This post is interesting for several reasons. First, it's the first time that the values and ethics of the DIY biology community are explicitly addressed in the forum. Second, the temporal trajectory of the community is made visible, at once concerning its current state ("nascent", "provisionally") as well as its future. Third, building a community for DIY biology is seen as a political and organisational/institutional endeavour. Fourth, the material and experimental facets of DIY biology is a key issue - the mission of finding, sharing, documenting and developing techniques and protocols discussed above. The post captures well the range of issues that are generally discussed on the forum, ranging from ethics to technology and organisational matters.

While questions about the practicalities of doing DIY biology - both in terms of organisation (8 topics) and equipment (8 topics) - are prominent in the discussions, other issues are also raised. For instance, in a topic titled *Cambridge DNA laws* (5 posts, 9 views) legal aspects are discussed: "We should investigate this and determine what the legal technicalities are concerning DIY Bio here in cambridge" (4/4/2008), "We definitely need due diligence about relevant legislation" (5/4/2008). Also, politics and the public image are addressed in the topic *Thoughts on public image* (12 posts, 8 views): "it's important that you get it right with the politicians from the start" (23/4/2008); "It would be nice if there was ONE politician we could pull aside and reason to informally; or keep on in an advisory role" (23/4/2008); "I agree with the importance of good press" (29/4/2008). Such concerns about the public's views on DIY biology reveal that right from its beginnings, the movement put efforts into "identity work" in order to clarify, represent and demarcate its identity.

4.2. What types of topics are posted and which kinds of issues are discussed?

We examined the active forms[6] used in the titles of all the topics. Algether 6549 terms are used, out of which about 3500 are used only once, about 5000 less than 4 times, and 540 at least 10 times. In the Appendix A, we list the top 100 terms used (which appear at least 35 times). The term most used is "fwd" (806 times), standing for "forward", a precious indicator of the origin of a message as its presence in the subject of a message allows us to deduce that there has been a transmission and import of information into the list. The author of the "forward" typically received a mail from a sender outside of the list - a mail containing for example information about an international conference, a local meeting or an interesting scientific article - and forwarded the mail to the other members of the list.

About two thirds of the top 100 terms fall into the following broad categories:

- science/organisms: diybio (737), science (258), dna (256), bio (250), biology (214), synthetic (151), cell (129), plant (102), sequence (101), gene (99), biotech (87), genome (85), protein (84), engineer (78), research (75), genetic (71), bacterium (63), biohacking (58), yeast (45), synbio (44), plasmid (42), molecular (39), coli (37)
- Qualifications: open (402), free (82), cheap (73), hack (66), online (37), access (36)
- Techniques and equipment: pcr (108), gel (80), equipment (71), electrophoresis (57), hardware (56), software (54), kit (54), microscope (50), machine (43), extraction (42), protocol (39)
- Places and meetings: lab (264), meet (103), group (81), home (73), biocurious (53), event (52), Boston (51), area (51), nyc [New York City] (46), sf [San Francisco] (43), meetup (39)
- Ideas and questions: project (163), need (89), question (75), idea (62), survey (54), request (39), find (37)

[6] The corpus of comments was analysed by selecting "active" word forms (such as nouns, adjectives and adverbs) and excluding "supplementary" word forms (like pronouns, prepositions, etc.).

- Academic dissemination: article (115), paper (62), talk (57), conference (50)

The first two categories confirm that the forum is concerned with sharing information about biology (in particular molecular biology) and that the kind of biology members wish to pursue is one that is open and accessible. The third category shows that the discussion forum is used for sharing knowledge about techniques, such as the PCR machine (which is the technique most frequently mentioned (108 times)). Many terms refer to specific places, be it general ones ("lab", "home"), specific ones ("Boston", "nyc"), or the activity of getting together in one place ("meet", "meetup") - showing that posting comments is also a way for people to communicate about concrete places and meetings. The terms we included in the category "ideas and questions" reveal the communicational practice involved: a member seeking information or testing an idea for a project. Finally, we also see terms that refer to academic ways of disseminating knowledge.

We posed the hypothesis that the members of the forum discuss a variety of issues, ranging from technical issues to social and political issues. In general terms, this is true. Issues beyond the scientific and technical aspects of DIY biology are discussed, such as:

- Economics and financial aspects: fund (31), kickstarter (23), startup (19), company (16), crowdfunding (15), business (12)
- Safety/security: safety (26), biosafety (14), safe (13), security (8), biosecurity (6)
- Regulation: law (15), regulation (15), legal (10), outlaw (6), legislation (3)
- Ethics: ethic (11), bioethics (10), ethical (6), responsible (4)

These terms are, however, not so frequent as terms that describe the practices and places of DIY biology. For example, safety is ranked 156th, ethic is ranked 437th, and security is ranked 606th. So while a range of issues are discussed on the forum, our analysis shows that some are more prominent than others - a question that we further examine in the following paragraphs.

4.3. What kinds of topics attract most replies and most views?

A great number of topics in the forum don't attract many comments. The average number of comments per topic is 6 and there are 1850 topics out of 6200 (30%) that consist of only one single comment. Those topics that have attracted most comments are listed in Table 1.

We classified the topics in this table according to their main theme. There are 16 topics that concern the use of specific techniques (Protein Shop, incubator, electrophoresis (2 topics), thermocycler, blenderfuge, microcontrollers, dremelfuge, PCR (3 topics), bioluminescence, ligation, spectrometer, Ames test, CCD resistance). 4 topics have to do with the use of biological components: plasmides, recombinant factor VIII, taq polymerase, and biobricks. Ideas for new projects - such as longevity, anti-ageng, biospheres, and testing e-cigarettes - are discussed in 4 topics, and the setting up new DIY biology groups in Perth and in Heidelberg are discussed in 2 topics. Finally, there are some issues that are discussed in only one topic: regulation/legislation, a news item, social issues, a call for applications, and an intrigue/game. We observe that, taken together, the use of techniques and biological components represent two thirds of the topics (20 out of 30). In other words, it is safe to say that topics about the practical means for carrying out experiments in DIY biology are of key importance in the forum.

Apart from the topics that have attracted most comments, we also examined which topics attracted most views. The topics are listed in Table 2.

There are 15 topics that concern the use of specific techniques: freezer, pipette, imageJ, liquid handling robot, techniques in general, water bath, DNA dissolution, sonication, petri dishes, DNA sequencing, electrophoresis, PCR, spectrometer (3 topics). The use of biological components - antibiotics, DI water, water, MitoTracker - is discussed in four topics. Finally, there are issues that are discussed in only one or two topics, including access to academic literature (2), social issues (1), safety (1), and definitions (2). As above, the use of techniques and biological components are important for the community (19 topics out of 30), which confirms our observation that the practical means for carrying out DIY biology are something that the members of the forum particularly value. In those topics concerned with the use of technologies, the first comment typically asks for help (to provide information to find a cheaper and more accessible alternative for a scientific technique, or to transform a tool) and responses then offer various kinds of advice and discuss various alternatives. The general mood and tone of the messages can be described as a form of "techno-optimism" coupled with a "shared responsibility" (see Southern et al., 2014).

While there is a striking similarity between the above two tables, there is one significant difference nonetheless. Among the topics that have attracted most views, there are issues about access to academic literature (the 1st and 4th topic) and about definitions (the 2nd topic). In other words, questions about basic knowledge are also important. While these questions don't attract that many comments (they are likely to be settled/solved easier) they are highly valued nonetheless.

Table 1
the 30 topics of the DIYbio discussion forum having received most comments.

Topic	Number of comments	Number of views
Engineering Plant Bioluminescence (was *Re*: experimentation)	91	593
DIY Longevity Project	87	192
Making my own incubator	85	584
YCombinator for Biotech Open now in SF (Indie Bio prev SynBioAxlr8r)	76	467
Protein Shop Help!	74	201
Get a plasmide - buy? share?	73	170
Perth (Australia) Group	71	411
Getting a sample ready for electrophoresis?	68	22
Help end harassment in hacking!	66	1183
$10 buck thermocycler design work	66	609
DIYbio projects	66	438
Blenderfuge	66	51
Microcontrollers	63	491
Paper electrophoresis... super available molecule separation?	63	286
What is the arcanum project?	63	15
help me setup DIY-BIO home Lab to produce Recombinant Factor VIII	62	604
Dremelfuge, the one-piece low-cost centrifuge	61	825
PCR trouble	61	98
Trible digest - ligation	61	18
DIYbio in Heidelberg, Germany	60	287
Administering anesthetic Agents to Mice	60	16
Openbiotech.com open source taq vector	59	484
Theranos, CEO Holmes, and Former President Balwani Charged With Massive Fraud	59	344
I had idea on biospheres.	59	151
RE: [DIYbio] Prospects of anti-aging research	58	654
Electronic requirements for redesign of Arduino PCR thermal cycler	57	414
What's wrong with open source PCRs	56	393
Transgenic CCD resistant honeybee - need help	56	251
thinking of ways to generate microstructures from bacteria	56	111
Ames test for e-cig e-juice...	56	96

4.4. How has the forum and its content evolved since 2008?

4.4.1. Analysis of the dynamics of exchanges

Fig. 6 shows the evolution of the forum in terms of the number of messages, topics and speakers over the years.

In the months that followed the creation of the forum (April 2008),

Table 2
The 30 topics of the DIYbio discussion forum having received most views.

Topic	Number of comments	Number of views
Downloading JoVE videos?	31	10,882
photospectrometer vs spectrophotometer... which is the standard term?	9	9740
How does MitoTracker Bind?	11	6981
Re: [DIYbio] (SciHub) paper/pdf access	2	6594
Which Antibiotics can be autoclaved	18	4907
What is DPBS, PBS, and HBSS?	12	4405
Boxbe notifications?	9	2648
Accessing raw data from the Emotiv EPOC EEG headset	4	2341
DIY deep freezer from mini fridge?	17	2300
Do-it-yourself NMR spectroscopy	10	2284
Cheapest way to get/make DI water?	8	2210
Cleaning methods for pipette tips	17	2180
Python alternative to ImageJ	14	2027
Ask a Biosafety Expert: A new service from DIYbio.org to get some free advice from biosafety experts	39	2015
Open Source version of VectorNTI	13	1782
One way to analyze 23andme raw data	18	1667
OpenTrons BioBot: Open-Source DIY Liquid Handling Robot!	17	1655
Cheapest and easiest way to do PCR at home?	43	1539
Re: Essential equipment for home genetic engineering?	9	1462
Lowering density of water	19	1430
Accurate Arduino-controlled Water Bath	31	1361
$800 USB UV/VIS spec Ocean Optics knockoff (re: nanodrops)	33	1215
Open-Source Spectrometer	51	1202
DNA dissolution problems	9	1185
Help end harassment in hacking!	66	1183
DIY Spectrophotometer	8	1167
DIY sonication? What is out there?	8	1167
Screw cap petri dishes?	17	1131
List of next-generation DNA sequencing companies	4	1117
A Cheap Source of Platinum Wire for Gel Electrophoresis Boxes	16	1105

the list begins to establish itself, with 133 speakers who send an average of 8,5 messages each. 2009 is a veritable turning point: during this period, the number of messages exchanged is multiplied by almost 6, the number of topics by 5, and the number of speakers by a little bit less than 3. Even if there is a slight decline between 2010 and 2012/2013, there still is a relatively large number of messages exchanged, which indicates a great dynamism within the forum. From 2013 onwards, we observe a significant decrease: there are 200 topics less (−25%) in 2014 than in 2013; the number of messages is divided by almost two between 2014 and 2015; and the number of speakers decreases from 2015 onwards (a number which had grown until 2014).

How to explain this decrease? One reason (which we could not verify) could be that some members of the forum lost interest in DIY biology and/or have moved on to do other things. Another reason, for which we found empirical evidence, is that many discussions now take place elsewhere. As new groups have been formed and laboratories been established, new communication channels and new mailing lists have also been created. On the discussion forum, people are for instance encouraged to subscribe to the mailing lists of the Sydney biohack group (in 2013), DIYbio-EU (2013), the Seattle group (2013), diybio-berlin (2014), DIYbio-Ireland (2014), BUGSS (2015), and the mailing list of the Waag Society in Amsterdam reportedly has over 1000 members (comment from 2017). The creation of the diybio-boston Google Group (which currently counts 263 members) was for instance advertised as follows:

> "Howdy Boston DIYbio-folk! I figured it was past time we established a local mailing list for coordinating meetings and making local announcements. [...] please join and use this new list for Boston announcements".

The comments under the topic *Why aren't DIYbio events being posted here? Regional DIYbio lists splinter the community* (2013) illustrate the issue - and potential problem - of new lists and groups forming:

> "Just found that a new biolab just opened up... yesterday. Why didn't anyone post this to the main DIYbio list? How is this really promoting openness? [...]" (comment 1)

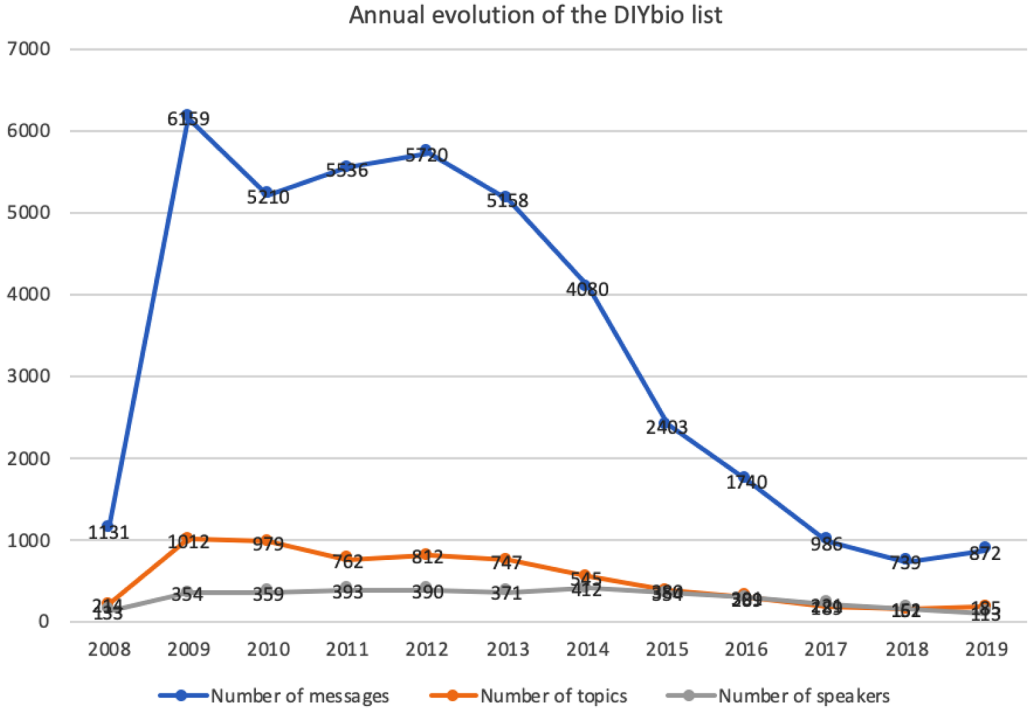


Fig. 6. evolution of the number of messages, topics and speakers.

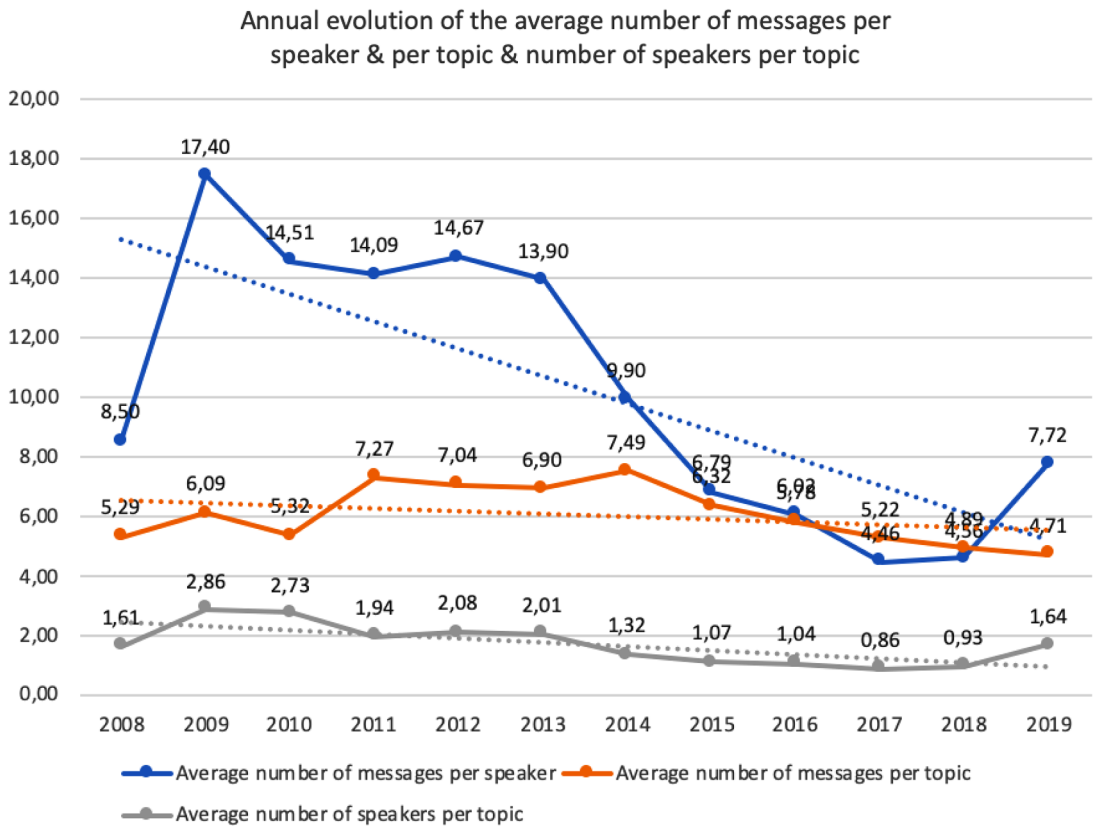


Fig. 7. evolution of the number of messages per speaker and per topic and the number of speakers per topic.

> "Fwiw [for what it's worth], I always cross post. Regional lists do make sense though- for events and the like. No need to spam everyone with our weekly emails" (comment 3)

> "[...] This is the typical fracturization of open communication channels (i.e. any community) – has happened before and will happen again. [...]" (comment 6).

While some discussions about DIY biology now happen in other places, this does not mean that the dynamics of the forum have decreased altogether. This can be evidenced by Fig. 7.

The average number of messages per topic (in orange) and speakers per topic (in grey) are not correlated with changes in the number of messages sent (in blue). Indeed, while the latter have fluctuated (and decreased) importantly, the dynamics of the former two curves show a relative stability within the timeframe observed. Thus, we can reasonably assume that we are faced with a rather homogeneous set of discussions which are characterized by a relatively small and stable number of speakers and messages. This hypothesis is validated by the fact that around 70% of the topics contain a number of messages that is equal or less to 6 and that the average number of speakers per topic is 1,67. To put it differently, while speakers have become less "talkative" over the years, the discussions, within given topics, have not become less dense.

4.4.2. Longitudinal analysis of the content

The longitudinal analysis (see Appendix D) of the topics posted on the DIYbio forum reveals two distinct phases. The first phase begins with the creation of the forum in 2008 and lasts until 2012. The second phase, which begins with the reconfiguration of exchanges in 2013 stabilizes until the end of our observation period in 2019. Throughout these two phases, there is a coexistence of two large lexical sets, one representing the sharing of information, the other with more technical content. The first corpus is about the transmission of information. The themes that make up this corpus are quite diverse: enriching knowledge via requests and suggestions for scientific articles and conferences, willingness to meet physically, etc. The second corpus focuses on technical aspects including equipment, raw materials, machinery, computers, and spaces.

In 2008–2009 (Appendix D - 2008–2009) almost 90% of the total number of messages are concerned with the transmission of information, and they are subdivided into two distinct corpora. In the fist corpus, the information transmitted concern methodological issues (with terms such as "source", "protocol", "engineer", "manufacture") and scientific issues ("scientist", "paper", "science"), in relation to particular fields, such as genetics ("dna", "gene", "protein", "cell"). As we saw previously with the predominance of the term "fwd" in the object of messages, certain members of the forum play the role of brokers by transmitting to their fellow members information that they have received via a channel outside of the forum. The flow of the information transmitted is "external-internal", that is, from the outside of the forum to the inside of the forum. Through the second corpus, we can observe the presence of a desire to meet physically, especially on the theme of diybio ("diybio", "synthetic", "synbio", "lab", "hacker"), and rather locally at the level of a city ("boston", "nyc", "seattle", "san francisco", "meetup", "regional", "week", "weekend"). The fact that these terms are directly inserted in the object of some messages suggests that some members can also become active organizers and actors of the DIY biology movement. The flow of information can be characterized here as being "internal-internal", that is, from the inside of the forum to the inside of the forum.

During the years 2010–2012 (Appendix D - 2010–2012), the above two corpora merge to form a new homogeneous corpus. In addition to the themes encountered in the previous period (concerning methods, knowledge, and encounters) we also observe new themes emerging, such as studies ("survey" in 2012) and 3D printing ("3D" in 2012). The second, less prominent corpus (representing 10% of the exchanges)

focuses on learning and enriching the group's knowledge. Financial aspects (“cheap”, “startup”), equipment (“kit”, “box”, “auction”, “microscope”, “spectrometer”), techniques (“electrophoresis”, “pcr”) and raw materials (“coli”, “food”, “straw”, “organic”, “enzyme”) are for instance mentioned in the second corpus.

Throughout the years 2008 to 2012, these two corpora reveal the local dimensions of people's engagement and interest in DIY biology, as well as the nature and usability of different kinds of data. Little by little, there is a growth of exchanges about experiences concerning fabrication methods and exchanges become increasingly precise, covering more restricted lexical fields (i.e. genetics, engineering, microscopy, bacteria), but still in a spirit of sharing and enriching common knowledge.

In 2013, a new period begins, which is characterized by a rebalancing of exchanges as well as a redistribution of certain themes, coupled with the consolidation of others. The corpus around the transmission of information only represents a little more than a third of messages in 2013. “Fwd” is no longer the most frequent term and slips into the background. The corpus now focuses on the sharing of knowledge in the field of genetics and meetings around biotechnology and open source. References to funding become also much more tangible (“crowdfunding”, “cost”, “free”, “patent”). The second corpus illustrates the consolidation and dissemination of the theme of genetics, which is discussed in almost all kinds and levels of exchanges. But it is the term diybio that really becomes the central theme in the exchanges between the members of the forum (present in more than a third of the messages). The specific organisation and characterization of diybio is also evident, with terms describing its autonomy (“community”, “project start”), institutionalization (“article”, “report”, “survey”, “event”) and internationalization (“eu”). At the same time, the notion of "biosafety" appears, which indicates a certain degree of maturation of the field since the safety of members in real-time experiments now becomes prominent. Starting from 2013, we witness the beginning of a phase where the knowledge shared in previous years becomes embedded, applied, and less theoretical. The experiences acquired and shared over previous years seem to find more practical implementations.

From 2014 until 2019, while the communicational flow on the forum decreases, the reconfiguration of exchanges stabilises. The transmission of knowledge remains a key element in-between members of the forum. However, at the same time, we note that the field is increasingly structured as a sustainable movement (“group”, “assembly”), that it is now more outward-facing (“opinion”, “event”) and that it continues its institutionalization ("academy", "residency", "visit"). The DIY biology movement has come to realise more than ever its role in popularising biological knowledge, enrolling laypeople, and educating an even larger public.

Overall, members of the forum discuss a range of issues. The forum is a place for sharing knowledge about techniques (how to find simpler, cheaper, more accessible equipment), protocols, tools, etc. It is also a device that people use to communicate about specific places and organize face-to-face meetings: members do not only *discuss about* DIY biology, they also *create concrete places for* DIY biology via the forum. While we found that members of the forum particularly value discussions about the practical means for carrying out DIY biology, we also found evidence that members have an interest in “basic knowledge” (access to academic journals, discussions about terminology). So while the members of the forum are particularly concerned with the *doing* of DIY biology, they also show interest in the *knowing* that underpins DIY biology.

5. Concluding remarks

This article has traced the beginnings, the rise and the evolution of DIY biology through online discussions. The forum aims at sharing information regarding biology (notably molecular biology) and values openness and accessibility. The first comments posted on the forum render explicit the key aims and objectives of DIY biology and provide insights of the movement's material constitution. We showed that discussions about the material means of DIY biology and organisational matters are prominent in these early discussions and a key aim was for people to get together and start doing things “on the ground”.

We were able to identify an important moment in the evolution of DIY biology in the years 2013 and 2014. In the existing literature, some elements have already been discussed, such as the inclusion of DIY biology in the iGEM competition (from 2014 onwards). But our paper has shown that many other elements come together at this moment: the creation of a high number of laboratories (21 are created in 2013 and 2014 alone), the rise of start-ups, and a significant change in the content of the forum. There is, on the one hand, a regional and economic structuration of the movement, coupled with an institutional recognition of the movement. On the other hand, through our analysis we observed an important decrease in the overall traffic on the forum (with less topics, messages and speakers) from 2013 onwards. These two dynamics - the structuration of DIY biology and the reduction of the forum's activity - are entangled: as new groups and labs emerge, some communication moves to new venues for discussion. The multidimensional and statistical analysis and the classification of text segments we performed showed that from 2014 until 2019, the lexical spheres used by the members reveal an increasing application, concretisation, and specialisation of the knowledge shared over the previous years. We thus argue that the emergence of DIY biology has known two distinct phases: a phase of constitution (2008–2012) and a phase of maturation and autonomisation (from 2013 onwards). While the first phase is marked by the local dimensions of people's engagement and by exchanges of knowledge and methods, the second phase is marked by more strategic efforts to sustain and institutionalize the community and by a more reflexive stance concerning its autonomy and positionality. The existence of these two phases, and the turning point in 2013/2014, is empirically evidenced by both qualitative changes (in terms of content) and quantitative changes (in terms of communication flows, number of labs, etc.). This result thereby confirms that the use of mixed methods is fertile to study the dynamics of a cultural movement through its online presence.

To finish, we would like to suggest three avenues for further research. First, with the methodological approach that we have developed in this article, we can imagine future work looking in more detail at the role of the movement's founding figures in the structuration of DIY biology, and providing a more fine-grained analysis of the dynamics of the main themes we observed. Second, there is a gap between the content of the DIYbio forum and the academic literature on DIY biology: while the former displays a concern with the sharing and documenting of both technologies and biological components, the latter has been mainly concerned with social issues (genealogies, identities, ethics, politics, democratisation, etc.). Further academic work thus needs to put the *doing* in DIY biology at the heart of its analysis and provide more empirical accounts of documentation and communication practices around technologies. Third, further academic work could examine in more detail the histories of groups, laboratories and projects dedicated to DIY biology. While this article has looked at the history of DIY biology as a whole via discussions on a forum, there is scope for comparing and contrasting our insights with dynamics at local levels (and perhaps also with other means of communication).[7] We hold that the temporal trajectories of DIY biology need further empirical tracing and theoretical problematization.

[7] There have been articles that focus on the constitution of individual laboratories (i.e. Bell et al., 2014; Landrain et al., 2013; Scheifele and Burkett, 2016), but they have mainly provided accounts of their organisation, projects, and members, leaving rather untouched questions to do with the history and transformations of laboratoires.

CRediT authorship contribution statement

Morgan Meyer: Conceptualization. **Frédéric Vergnaud:** Methodology, Software.

APPENDIX A. The top 100 active terms and their occurrences in the titles of the topics

fwd;806 diybio;737 diy;416 open;402 lab;264 science;258 dna;256 bio;250 biology;214 source;172 project;163 synthetic;151 cell;129 article;115 pcr;108 what;107 meet;103 plant;102 sequence;101 gene;99 need;89 biotech;87 genome;85 protein;84 free;82 community;82 interest;81 group;81 gel;80 start;79 engineer;78 call;76 research;75 question;75 home;73 cheap;73 genetic;71 equipment;71 design;71 test;70 hack;66 culture;66 bacterium;63 paper;62 idea;62 list;60 datum;60 human;59 patent;58 biohacking;58 talk;57 electrophoresis;57 build;57 hardware;56 video;54 survey;54 software;54 kit;54 biocurious;53 update;52 grg;52 event;52 synthesis;51 igem;51 boston;51 area;51 space;50 microscope;50 conference;50 week;49 system;49 workshop;48 work;47 scientist;46 nyc;46 yeast;45 live;45 synbio;44 manufacture;44 sf;43 machine;43 plasmid;42 extraction;42 tt;40 biohackers;40 base;40 request;39 protocol;39 molecular;39 meetup;39 life;39

3d;39 good;38 online;37 find;37 coli;37 food;36 access;36 summer;35 print;35

APPENDIX B. List of DIY biology labs (unless marked otherwise, the source of data is https://sphere.diybio.org)

Name	Year	City	Country
[kat]alab Vienna	2017	Vienna	Austria
Art Science BLR	2009	Bangalore	India
Bio Art Laboratores	2012	Eindhoven	Netherlands
Bio Foundry	2014	Alexandria	Australia
BioBlaze Community Bio Lab	2017	South Elgin	USA
Biocurious	2010	Santa Clara CA	United States
Biodidact	2014	Los Alamos	United States
BiologiGaragen	2010	Copenhagen	Denmark
Biologik Labs	2013	Norfolk	United States
Biomakers Lab Peru	2014	Lima	Peru
Bionest	2018	Irapuato	Mexico
BioNyfiken	2014	Stockholm	Sweden
Bioscope	2014	Geneva	Switzerland
Biotech Without Borders	2017	Brooklyn	United States
BioTehna	2013	Ljubljana	Slovenia
BioTown	2017	Ottawa	Canada
BosLab	2014	Somerville	United States
Bricobio	2013	Montreal	Canada
Brmlab	2010	Prague	Czech Republic
Bugss	2013	Baltimore	United States
BuiQuisitive	2015	Brunswick	Australia
Capital Area BioSpace	2015	Reston	United States
Charlottesville Open Bio Labs	2015	Charlottesville	United States
ChiTownBio	2017	Chicago	United States
Counter Culture Labs	2013	Oakland	United States
Denver Biolabs	2015	Denver	United States
DIY Bio Barcelona	2014	Barcelona	Spain
DIYbio Toronto	2013	Toronto	Canada
DIYbioTech	2013–2016	Longwood	United States
F.lab	2015	Bangkok	Thailand
Forma Labs	2014–2015	Cork	Ireland
Garoa Open BioLab	2011	Sao Paolo	Brazil
GaudiLabs	2011	Lucerne	Switzerland
Genspace	2010	Brooklyn	United States
Hackuarium	2014	Renens	Switzerland
HiveBio	2013	Seattle	United States
Indie Lab	2012	Richmond	United States
Just One Giant Lab	2015		France
L'Eprouvette*	2005	Lausanne	Switzerland
La Jolla Bio Lab	2015	La Jolla	United States
La Paillase	2011	Paris	France
La Paillase Saône	2015	Villeurbanne	France
LifePatch	2012	Yogyakarta City	Indonesia
London Biohackspace	2009	London	United Kingdom
MadLab Biolab	2011	Manchester	United Kingdom
Open bioLab Graz Austria	2013	Graz	Austria
Open Science Network	2010	Vancouver	Canada
Open Wetlab	2012	Amsterdam	Netherlands
Ottawa Bio Science	2018	Ottawa	Canada
PechBlenda Lab	2013	Barcelona	Spain
ReaGent	2015	Gent	Belgium
SoundBio Lab	2016	Seattle	United States

Symbiolab	2014	Maribor	Slovenia
The LAb	2011	Los Angeles	United States
Top	2017	Berlin	Germany
TrySci Community Biolabs	2014	Independence	United States
Turbine Bio Lab	2018	Newcastle	England

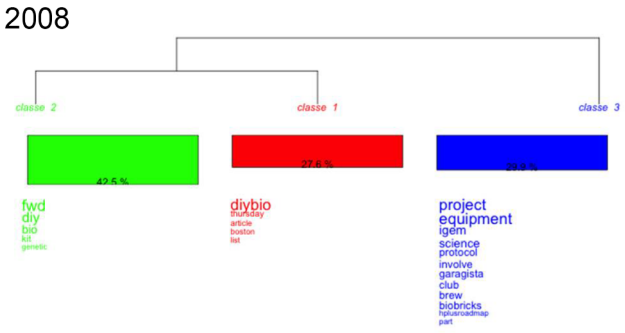
*We have not included this laboratory in our analysis since it predates the creation of the DIY biology movement.
Other sources consulted apart from https://sphere.diybio.org: Brmlab: http://brmlab.cz/start; Capital Area BioSpace: https://www.meetup.com/fr-FR/CapitalAreaBioSpace/; F.lab: https://www.facebook.com/pg/FLabDIYbioThailand/about/?ref=page_internal; GaudiLabs: https://wiki.hackerspaces.org/GaudiLabs; MadLab Biolab: https://madlab.org.uk/community-biotechnology/; PechBlenda Lab: https://network23.org/pechblendalab/crono-safaris/.

APPENDIX C. List of start-ups

Name	Year	City	Country
AlgiKnit	2017	New York	United States
allevi	2014	philadelphia	united states
Amid biosciences	2016	santa clara	united states
Amino Labs	2015	Lethbridge	Canada
Bento Lab	2014	London	United Kingdom
Billion to One	2016	Palo Alto	United States
Biomeme	2013	Philadelphia	United States
Cell Eleven	2016	Philadelphia	United States
Chai Bio	2016	Santa Clara	United States
Chronomed	2016	Amsterdam	Netherlands
Clear Gene	2014	San Francisco	United States
Combimmune	2012	Palo Alto	United States
Conector Ciência	2017	Rio de Janeiro	Brazil
Digi.Bio	2017	Amsterdam	The Netherlands
Ecovative Design*	2007	Green Island	United States
Eligo Bioscience	2014	Paris	France
Feles	2018	Boston	United States
Folia Water	2016	Oakland	United States
Folium Biosciences	2015	Colorado Springs	United States
Hyasynth Biologicals	2014	Montréal	Canada
Innovative Medicine*	2004	New York	United States
Kilobaser	2014	Graz	Austria
Lederer-Stark Innovations GbR	2018	Allmersbach im Tal	Germany
Microsynbiotix	2016	San Diego	United States
Open Trons	2014	New York	United States
OpenBionics	2014	Bristol	United Kingdom
PILI	2014	Paris	France
Prospective Research	2015	Beverly	United States
Quantgene	2016	Berkeley	United States
RotterZwam	2017	Rotterdam	Netherlands
SE3D	2014	San Francisco	United States
The ODIN	2016	Oakland	United States

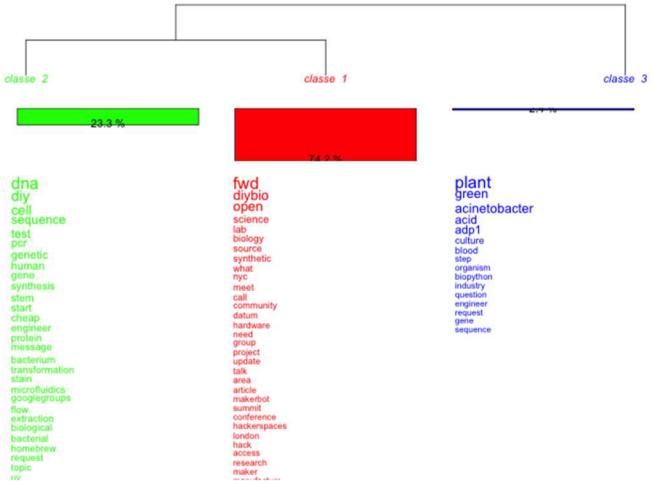
*We have not included these two start-ups in our analysis since their creation predates the creation of the DIY biology movement.

APPENDIX D. Chronological analysis of the topics posted on the DIYbio forum (2008–2019)

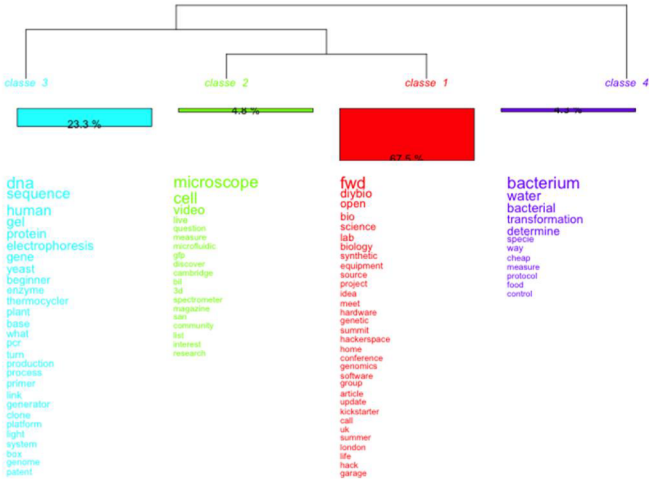


2009

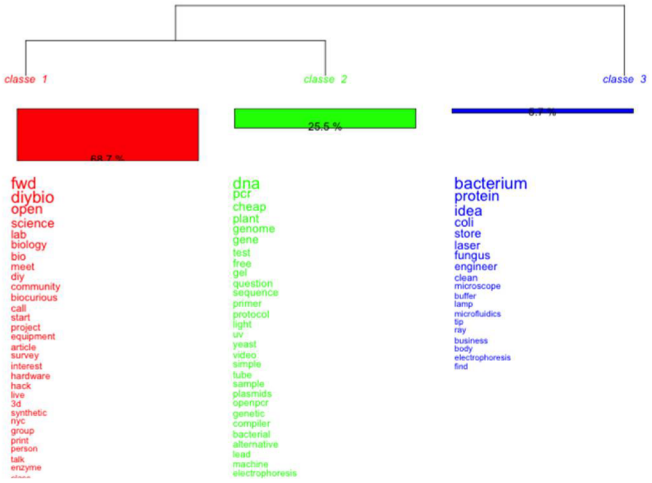
2010



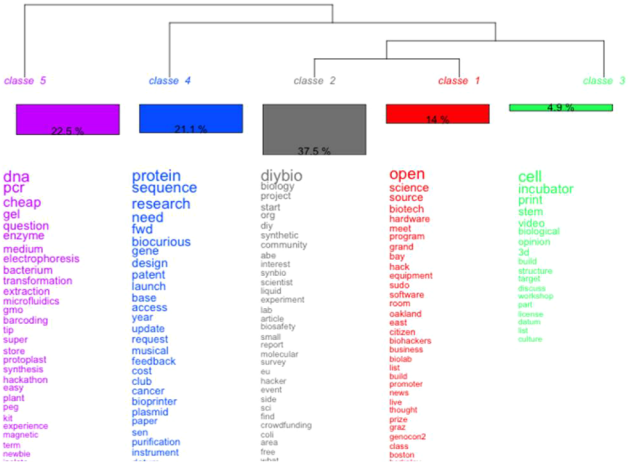
2011



2012



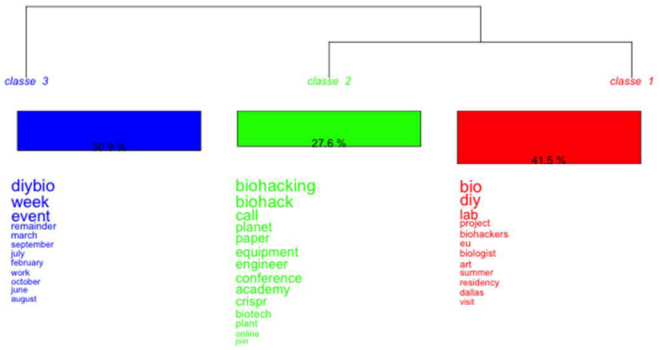
2013



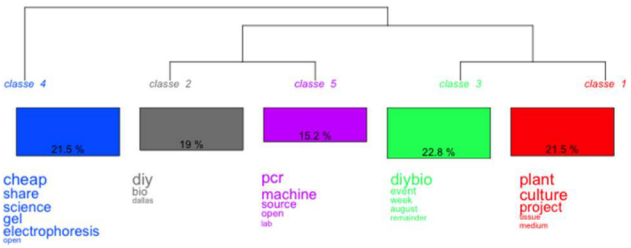
2014

2015

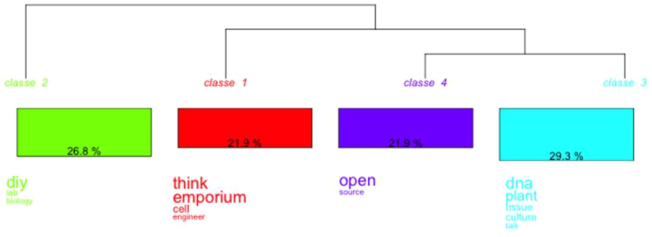
2016



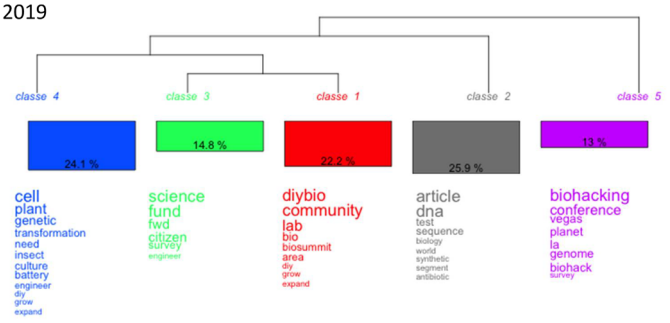
2017



2018



2019



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