

Knowledge across networks: how to build a global neuroscience collaboration

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Highlights

- The International Brain Laboratory (IBL) is a flexible, distributed, and predominantly virtual network of neuroscientists studying decision-making and the mouse brain.
- IBL researchers (postdocs, students, staff) are a diverse group of scientists essential for sustaining and refining this collaborative network.
- Intersecting knowledge domains (formal, contextual, experimental, theoretical) are critical for successful collaborative neuroscience research.
- Flat organizational hierarchies encourage researcher advocacy, to refine and reform research culture and scientific practice.

Abstract

The International Brain Laboratory (IBL) is a collaboration of ~20 laboratories dedicated to developing a standardized mouse decision-making behavior, coordinating measurements of neural activity across the mouse brain, and utilizing theoretical approaches to formalize the neural computations that support decision-making. In contrast to traditional neuroscientific practice, in which individual laboratories each probe different behaviors and record from a few select brain areas, IBL aims to deliver a standardized, high-density approach to behavioral and neural assays. This approach relies on a highly distributed, collaborative network of ~50 researchers—postdocs, graduate students, and scientific staff—who coordinate the intellectual, administrative, and sociological aspects of the project. In this article, we examine this network, extract some lessons learned, and consider how IBL may represent a template for other team-based approaches in neuroscience, and beyond.

Introduction

The International Brain Laboratory (IBL) was founded with the goal of understanding how the brain operates to drive decision-making behavior [1]. Decision-making behavior demands information about sensory stimuli, reward expectation, and prior experience, processed by millions of neurons within local circuits and across brain regions. Fully understanding these processes is of a scale and complexity far exceeding what can be tackled by any single laboratory. As such, the IBL's approach is to implement a distributed research architecture across a global network of laboratories to assay how decision-making behavior is encoded in

the mouse brain. This architecture combines a high-throughput behavioral task with high-density neural recordings, standardized anatomical mapping, and collaborative code repositories for analysis and modeling—all alongside a commitment to publicly deposit our data, tools, and resources for everyone to use.

The collaboration is currently distributed over 22 laboratories across six countries, with each location hosting several members who implement IBL tools and resources within the existing laboratory infrastructure. Our network has unified the efforts of nearly 80 neuroscientists to develop an experimental ecosystem generating high-throughput behavioral data in mice [2], a pipeline for acquiring large-scale, high-density neural recordings during behavior, and a public-facing digital architecture to host these data [3].

IBL was organized because ‘team science’ consistently demonstrates high impact [4], innovation [5], and productivity [6]. As a distributed team model, we have coalesced resources around a unifying scientific question while also accommodating members’ autonomy within traditional institutions, where full interdisciplinary collaboration can be cumbersome to implement [7,8]. The result is a low-hierarchy organization of scientists that remain independent in skills, research interests, and physical location, who contribute individual expertise toward a shared methodology and develop a common vocabulary in order to communicate across large-scale projects [9,10].

Specifically, transmuting team-science philosophy into tangible outputs is due to the efforts of IBL’s scientific researchers. Postdocs, graduate students, and scientific staff have built a complex, grassroots team-science apparatus [11] that lets us connect existing labs and traditional institutions, distribute tasks and resources, and produce resources for the greater scientific community. As our collaboration enters its fourth year, we take this opportunity to examine its organizational structure, extract the lessons learned, and understand how it may serve as a model for other team-based approaches in neuroscience (Box 1).

‘Researchers’: a unified identity

Alongside the 22 faculty members who lead their lab’s participation in the collaboration, ~50 additional IBL members are responsible for the collaboration’s day-to-day scientific activities. Many studies differentiate science workers by career stage [12], but we found common terms like ‘early career researchers’ or ‘trainees’ failed to capture the breadth and variety of experience in our cohort. This group includes postdocs, students, technicians, staff, software developers, and industry contractors, each with different scientific vocabularies, lab experiences, and educational backgrounds. Despite these differences, many of us participate at the front lines of many different scientific activities such as writing software, building hardware, recording neurons, handling animals, leading team meetings, analyzing data, or writing papers—to name only a few. As such, we collectively identify as ‘researchers’. Applying a single unified identity across traditional academic boundaries has greatly influenced the knowledge

exchange across the collaboration, and has expanded our definition of what constitutes scientific work.

Local and global crossover

IBL researchers are a mix of members who contribute full- or part-time to IBL initiatives. A small core of full-time IBL staff members develop and maintain key platforms for IBL research, like data architecture or technical infrastructure. Of the ~30 postdocs and graduate students, roughly half work full-time on IBL-specific scientific projects, while the rest share their time between IBL projects and research in their local labs. Our research technicians, software developers, and industry contractors also divide their efforts between both local and IBL research activities.

Since researchers participate in a local research environment while also participating in IBL's, the boundary between local and IBL-wide activities is permeable. This enables research cultures to intersect and encourages exchange with other systems neuroscience initiatives beyond IBL. For instance, while we acquired expertise from our local labs to inform IBL's standard experimental protocols, we liaise with other neuroscientists who want to adopt the resulting tools [2] for their own projects. Crossover efforts between projects within and beyond IBL have been an opportunity for us to collectively develop and refine approaches across systems neuroscience more broadly.

Making a virtual space

Compared to collaborations that develop their practices within a single physical institution [13], IBL developed across multiple, distributed locations and relies on a virtual group [14]. The IBL virtual environment resembles other modern 'postwork' environments, in which digital sharing bends the spatial and temporal boundaries of the workplace [15]. The collaboration itself is physically distributed across 16 institutions and nine time zones, but real-time online connectivity erases these boundaries and instead supports a centralized space where IBL members, irrespective of physical location, regularly convene to maintain knowledge and share resources. Just as in a traditional laboratory, members collectively manage a mix of interdependent empirical, technical, and administrative tasks, all united by a set of scientific goals.

Our virtual environment is scaffolded by a combination of Slack (real-time messaging), Google GSuite (documentation), Zoom (video conferencing), Github (code repository), and Datajoint and Alyx (experimental databases). While these tools are an indispensable part of IBL's online environment, we still periodically utilize one or two traditional in-person meetings each year to build cohesion and community beyond digital spaces. Our annual meeting convenes all members to discuss scientific milestones and team-wide policies, while an annual researcher summit affords an independent space to navigate the successes and challenges specific to postdocs, students, and staff.

Flat hierarchies facilitate access

IBL's virtual environment has grown to accommodate a diversity of scientific activity, and is supported by a flexible, 'flattened' hierarchy (Figure 1) that emphasizes horizontal relationships over vertical management [16]. This structure is directly inspired by the ATLAS collaboration at CERN, which has a voting assembly to ratify decisions, an executive body managing operations, and a flexible network of specialized subgroups [17]. Similarly, small teams of IBL members collaborate on projects in Working Groups (WGs), which are defined around particular specializations and milestones (Table 1) and coordinated jointly by a chair and associate chair (typically a PI and researcher, respectively). All WG chairs sit on the Executive Board to propagate decisions across WGs, facilitate operational and financial support, and prepare proposals for voting by the General Assembly, which represents all PIs. In parallel, associate chairs convene on their own committee to share decisions, which are then conveyed to the entire researcher community so it may weigh in on proposals before a formal vote. The interests of PIs and researchers intersect via staff liaisons who sit on both the Executive Board and the Associate Chairs Committee, as well as an elected researcher representative, who sits on the Executive Board and is a voting member of the General Assembly.

IBL's governance structure is complemented by our use of "sociocracy", a form of dynamic consent-based decision-making that encourages members to iteratively create actions that are "good enough for now, safe enough to try" [18]. Proposals are developed by PIs and researchers alike, from all corners of the collaboration, and are announced in team-wide spaces to facilitate input not only from vested stakeholders or formal representatives, but by all IBL members directly. This model of rapid iteration, stakeholder crossover, and direct access has made it easy for researchers to interact and support each other on various tasks and policies. It has also diminished the hierarchy between PIs and researchers, facilitating access to senior members for other, broader goals—scientific engagement, academic supervision, and professional support.

Knowledge occupies people and places

Across our virtual environment, information in the IBL is open—all records are accessible by any member, irrespective of position or length of membership. While this open access has facilitated a culture of transparency [19], the total amount of information generated within the collaboration presents an enormous practical obstacle: as of April 2020, there were 34,478 public Slack messages; 363 recorded Zoom meetings; 187 presentation slide decks, 233 spreadsheets, 1,618 text documents, and 7,603 PDFs in GSuite; 6,148 Github commits; and over 500,000 experimental files in Datajoint. The IBL ecosystem, like other biological and social systems, is a network [20], but successfully distributing this much information across it is a daunting proposition.

Two essential features coordinate this information to better serve our organizational decision-making, learning, and memory [21]. The first is our constellation of Working Groups

that maintain and distribute local, specialized knowledge to other groups across the network. Since each IBL researcher typically participates in three or four Working Groups, there is a high degree of information exchange, which juxtaposes related initiatives and complementary expertise (Figure 2). A second, more emergent property is the subgroup of IBL researchers who have become experts, liaisons, and interpreters of knowledge across the network [22]. These members each manage a domain of explicit records (e.g., written protocols) and tacit information (e.g., colloquialisms, decision histories) that are quickly and informally disseminated to address real-time needs and problems. A remarkable nimbleness is afforded by this system of rapid responders deployed across our web of Working Groups. However, this kind of internalized knowledge can be vulnerable to drop-out when people leave the collaboration, and can be complex to archive [23]. An ongoing challenge for our collaboration is how to archive both our explicit and tacit processes held in both people and places. This is not only to document our own history but as part of a roadmap for future science teams, whose dynamics are still not fully understood [24].

Strengthening formal knowledge with context

In traditional laboratories, a mix of both academic trainees and staff seems to foster scientific progress [25], which can be attributed to the exchange of trainees' 'formal' knowledge of scientific phenomena (e.g., theories, papers, or grants) with staff's 'contextual' knowledge of how those phenomena manifest in the lab (e.g., materials, instruments, or techniques) [26]. Knowledge is similarly allocated within IBL in that trainees focus on generating papers and staff focus on maintaining infrastructure, but in a flat hierarchy, this allocation is flexible. IBL trainees regularly engage with instrumentation or back-end software development, while staff often participate in experimental design, data visualization, or analysis. This exchange enables a more comprehensive understanding of data generated in our laboratory spaces. Take, for example, a recent staff-postdoc collaboration that synthesized animal husbandry techniques and behavioral analysis: *ad libitum* access to 2% citric acid water works as well as traditional water restriction for task-performing mice [27].

Across science, increasingly capricious funding and a hypercompetitive trainee pipeline have arguably led to a culture of conservative, short-term scientific returns [28]. However, diversifying the laboratory with researchers with complementary skills and career trajectories could help guide a shift toward more creative, sustainable scientific growth. Many scientific questions being addressed are also too ambitious to be tackled by a single trainee, and are increasingly relying on large, longitudinal research teams concentrated in physical institutes like Janelia Research Campus [29] and the Allen Institute [13]. While physical proximity between collaborating researchers has its advantages, IBL's distributed model allows team composition to be adjusted more flexibly and nimbly, drawing together talents from around the world. Indeed, our own platform papers [2,3] highlight the sheer diversity of researchers needed to complete these large-scale projects. Expanding researcher roles beyond trainees should be a central goal if our field wishes to stabilize large-scale collaborative science in traditional academia [30]; it is

promising to consider the new types of researchers we can attract if we don't need to bring them into a single lab, but rather can bring the lab directly to them.

Experiments need theories, and vice versa

If formal-contextual exchange is one axis of IBL's knowledge sharing, another is the interchange between theory and experiment, an implicit partnership underlying all scientific outputs [31]. On one hand, theory can be iterated to produce models that satisfy constraints imposed by empirical data; on the other, experimentation is disciplined by hypotheses generated from models. Addressing this directly, a critical IBL mandate [11] is to ensure that theory and experiment converge at the ground level, and perpetually throughout our scientific process.

Although most IBL member labs still largely identify as either 'experimental' or 'theoretical', IBL's virtual network means that experimental and theoretical researchers are constantly interacting. An experimentalist/theorist 'buddy system' offers a low-stakes, one-on-one partnership where we can ask each other general or introductory questions, while further crossover is encouraged through an online computational neuroscience course led by theorists for experimentalists, and a sabbatical initiative, where a researcher can embed within a partner lab to learn firsthand new concepts. Sharing theory-experiment spaces on multiple levels has allowed researchers to synthesize biological and mathematical vocabularies to develop a common language that bridges this traditional divide. Maintaining this crossover should continue to help us derive more complete neuroscientific answers, but also formulate more relevant questions [32].

Committing to transparent histories

Scientific findings result from the culmination of many actions that generate theories, data, analyses, and interpretations. However, a complete history of these actions is rarely ever recorded—this could be due to long research timeframes [33], short institutional memories [34], space constraints in a 'single, flat PDF' [13], or a reward system that favors paper counts over good laboratory habits [35–37]. It is possible that incompletely recording and reviewing actions in the lab could contribute to irreproducibility in systems neuroscience [38–40] and science in general [41–43].

How, then, to produce a more transparent and documented scientific process? Two elements of IBL's approach seem to hold promise. First, the connections between researchers and Working Groups (Figure 2) afford a great deal of redundancy in our information transfer, and enable us to examine findings through a diversity of experimental, technical, and theoretical lenses. Multiple researchers interact with bits of data or theories as they emerge, and while this process generates a rich complex of individual contributions, it invites many members into collective responsibility for any single scientific result [44]. Second, we have built publication and data policies that mandate public sharing of data, methods, code, and software, as well as open-access publications via Plan S [45]. This ensures that our findings are shared with communities of both scientists and the public for further analysis and inspection, as a "trust technology" [46].

Maintaining complete and transparent histories for our platform projects has been particularly demanding given their size and scale. The number of contributions that any single researcher makes to an IBL project far exceeds what is typically enshrined in print. IBL's behavioral platform paper [2], for instance, has 26 researchers named as coauthors and a contribution statement of over 1300 words (consider that *Nature's* current [formatting guidelines](#) recommend "several sentences"). This is strong evidence that scientific collaborations are outgrowing the limitations of traditional authorship, which will require expanding our taxonomies of credit [47] and creatively managing the diverse efforts that go into large-scale projects. An ongoing IBL effort is to develop a comprehensive credit-assignment system that reflects a spirit of collaboration while also providing meaningful signifiers of individuals' work that translate beyond the collaboration.

Advocating for change

Developing a successful credit-assignment system is just one of many ongoing evolutions in IBL—most of them spearheaded by researchers. Despite the already-immense job pressures [48], we spend considerable time assessing IBL practices and proposing overhauls through a combination of annual reports and real-time proposals. We have led actions on project registration and organizational record-keeping; policies on environmental responsibility, safety climate, diversity and inclusion, and professional development; and even petitions to scientific journals to expand guidelines to accommodate IBL's authorship scheme. Cultivating advocacy alongside science research may be one of the enduring touchstones of IBL's collaborative model, providing next-generation scientists with agency to tackle the issues in academia and reinvent a beleaguered system. IBL's model has already provided fertile ground for testing many new scientific practices. Perhaps the next iteration will have even less resemblance to traditional science, further pushing toward a fully collaborative, reproducible, and open endeavor—and making room for an even greater diversity of scientists who come after us.

Data and code availability

Network analysis was completed using NetworkX [49] and Plotly [50] Python libraries. Data and code are available on Figshare (https://figshare.com/projects/IBL_Network_Analysis/84239).

Acknowledgments

Many thanks to all of the IBL researchers for rich discussions over the past three years that helped shape the structure and message of this article. Particular thanks goes to Z.C. Ashwood, H.M. Bayer, G.A. Chapuis, M. Häusser, A. Pouget, M.M. Schartner, A. Urai, and M.R. Whiteway for constructive comments on the manuscript. L.E.W. is a member of IBL, which is funded by the Simons Foundation and the Wellcome Trust. L.E.W. is also supported by a Marie Skłodowska-Curie Actions individual fellowship (no. 795846).

Declarations of interest

The authors declare no competing interests.

Figures

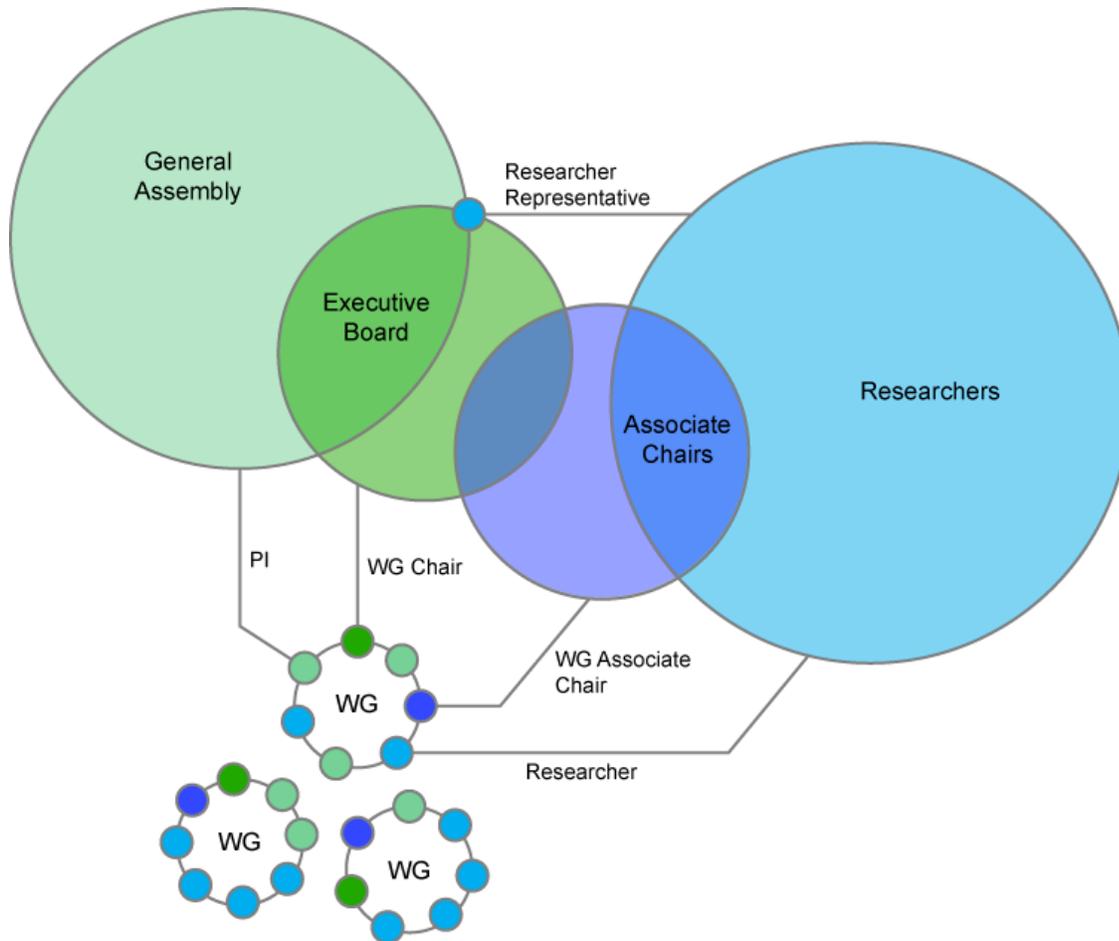


Figure 1. The IBL 'flat hierarchy' model. On a day to day level, small teams of IBL members collaborate on projects in Working Groups (WGs), which are defined around particular specializations and milestones (Table 1) and coordinated jointly by a chair and associate chair (typically a PI and researcher, respectively). Decisions and proposals generated in WGs take two parallel paths through the organization. For PI-focused stakeholder groups (green), WG chairs convene on the Executive Board to share decisions across WGs, facilitate operational and financial support, and formalize proposals for voting by the General Assembly, which represents all PIs. For researcher-focused stakeholder groups (blue), associate chairs convene to share decisions across WGs, which are then conveyed to all researchers for a chance to influence proposals directly. PI and researcher interests interconnect via staff liaisons who sit on both the Executive Board and the Associate Chairs Committee, as well as by an elected researcher representative, who sits on the Executive Board and is a voting member of the General Assembly. Lines between groups illustrate how stakeholders are represented in WGs; for clarity, only a few lines for one WG are shown.

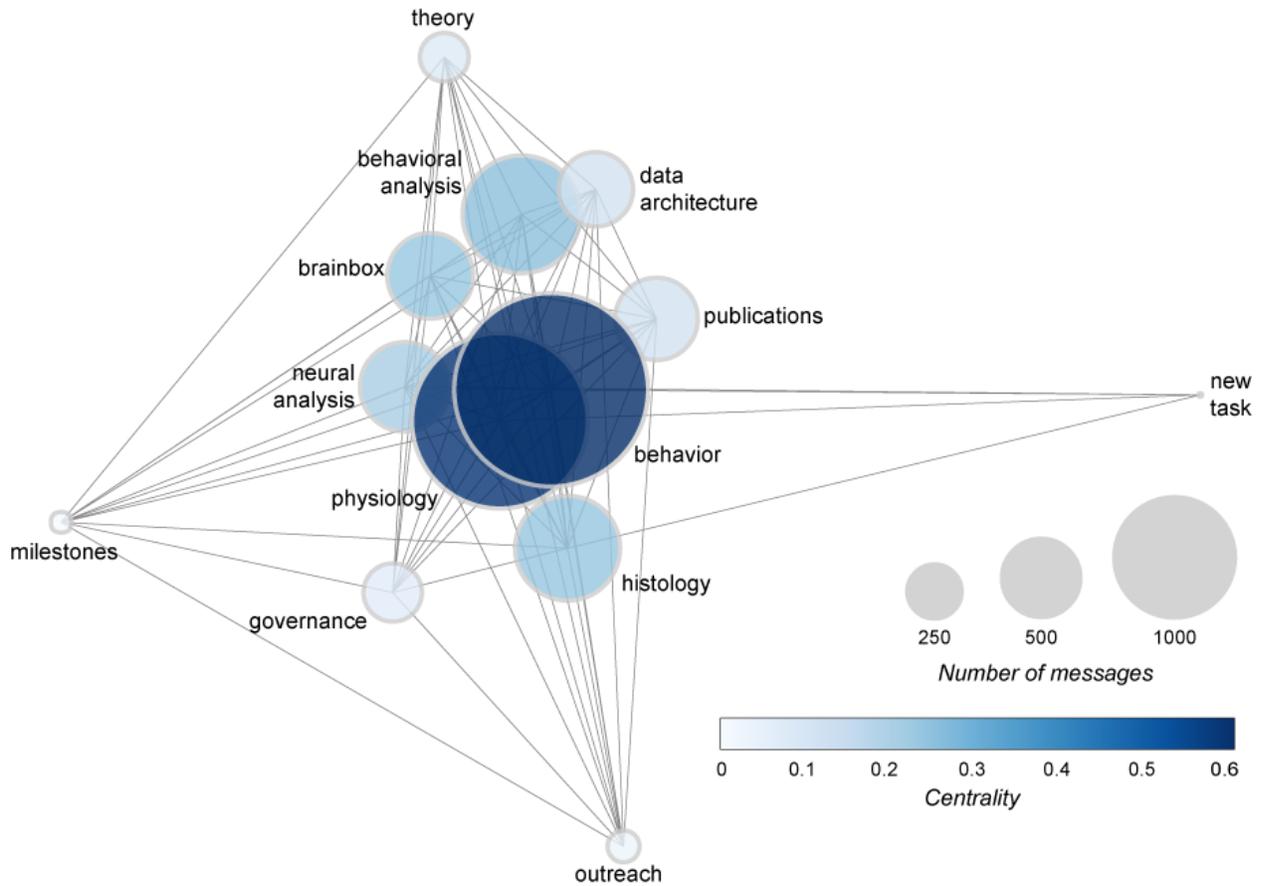


Figure 2. IBL’s network of Working Groups, as viewed through 9,226 Slack messages sent by 41 researchers to 13 Working Group channels (August 2016-April 2020). Each node represents a working group, and each edge between two nodes represents a researcher who messaged both groups. Since some researchers message more than others, each researchers’ message count was normalized as a proportion. Researchers who sent no messages to these channels were omitted from analysis. Node position and edge length were determined using edge weight, which was computed as the product of message proportion between the edge’s two nodes. Node shade represents the eigenvector centrality as determined from the weights of all connected edges. Node size reflects the absolute message count to that group. Connections between Working Groups are stronger (shorter edges, higher centrality) when they share more researchers and/or messages, and weaker (longer edges, lower centrality) when they share fewer researchers and/or messages. Data for this analysis is available in Google Colab (see ‘Data and code availability’).

Box 1. Ten thoughts on building a large-scale scientific collaboration.

1. Develop common language to connect your team. Overlapping Working Groups help build shared technical vocabularies, and using a single 'researchers' label connects many different IBL scientists with different experience, education, and career trajectories.
2. Keep a flexible boundary between internal and external projects. Giving ourselves time to engage in both IBL and local lab projects has broadened the uptake of our resources and involved many outside colleagues as collaborators.
3. Create and maintain a centralized environment to exchange knowledge and build community. For virtual teams like ours, this has required several different online tools and information formats.
4. Keep organizational hierarchy 'flat' so different stakeholders can interact and influence policy. We broadly distribute decisions through parallel channels and share policy centrally so that each member can contribute directly or through a representative.
5. Cultivate information in different spaces across your organization, and anticipate that some team members will become key facilitators of this information. Working Groups are essential bodies of specialized knowledge in IBL, and 'expert' members connect others to this knowledge.
6. Acknowledge that organizational knowledge occupies different forms, locations, and people, which makes archiving complex and challenging. Despite this, commit to documenting your process. IBL members are constantly refining strategies for documenting decisions and project progress.
7. Anticipate that developing large-scale resources will require a diversity of efforts and a rich crossover of knowledge domains. Make space for those in one domain to contribute to another. Crossovers between formal vs. contextual knowledge, as well as experimental vs. theoretical knowledge, are constant features of IBL projects.
8. Adhere to open-source principles and make public sharing a foundational expectation. This will diminish organizational boundaries, encourage transparency, and expand your impact. IBL's data and publication policies mandate public sharing, to broadly inform neuroscience and influence research culture in general.
9. Prepare to longitudinally track contributions to projects as they grow, and utilize a taxonomy that can accommodate new, unique and diverse contributions. The IBL behavioral platform paper has been documenting contributions for nearly 12 months, and is actively developing a comprehensive credit-assignment policy for its platform papers.
10. Make the changes needed to push your team forward. Alongside science work, IBL researchers routinely advocate to improve research culture and respond to issues facing scientific practice both within and beyond the collaboration.

Table 1. Working Groups and objectives as of April 30, 2020.

Name	Objective	Created
Governance	Manage, review and help implement policies for the collaboration's function	25 August 2016
Neural Analysis	Analyze neural data	7 September 2016
Publication	Develop policies and guidelines pertaining to scientific communication, authorship, and credit	14 September 2016
Physiology	Develop tools and protocols for neural recordings	25 September 2016
Behavior	Develop and deploy the behavioral task in member labs	10 January 2018
Behavioral Analysis	Curate, visualize, and analyze behavioral data	16 July 2018
Data Architecture	Design and implement the platform for hosting and sharing IBL data	20 March 2019
Histology	Design and implement processing pipeline for analyzing post-experiment brain tissue	20 March 2019
Theory	Develop canonical models for animal behavior and neural activity	20 March 2019
Brainbox	Develop and curate a Python toolbox for neural and behavioral analysis	17 June 2019
Outreach	Coordinate activities for scientific communication and public engagement	24 September 2019
New Task	Discuss and develop future behavioral tasks	21 November 2019
Scientific Milestones	Discuss and develop future projects under the IBL banner	17 December 2019

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