The COVID-19 pandemic has profoundly affected life worldwide. Governments have been faced with the formidable task of implementing public health measures, such as social distancing, quarantines, and lockdowns, while simultaneously supporting a sluggish economy and stimulating research and development (R&D) for the pandemic. Catalyzing bottom-up entrepreneurship is one method to achieve this. Home-grown efforts by citizens wishing to contribute their time and resources to help have sprouted organically, with ideas shared widely on the internet. We outline a framework for structured, crowdsourced innovation that facilitates collaboration to tackle real, contextualized problems. This is exemplified by a series of virtual hackathon events attracting over 9000 applicants from 142 countries and 49 states. A hackathon is an event that convenes diverse individuals to crowdsource solutions around a core set of predetermined challenges in a limited amount of time. A consortium of over 100 partners from across the healthcare spectrum and beyond defined challenges and supported teams after the event, resulting in the continuation of at least 25% of all teams post-event. Grassroots entrepreneurship can stimulate economic growth while contributing to broader R&D efforts to confront public health emergencies.

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were from low and middle-income countries (LMICs). Each event facilitated the organic formation of approximately 200 teams spread across 10 tracks, each with challenges identified in conjunction with partners and stakeholders. An average of 70 partners were recruited for each event ranging from universities, hospitals, and health systems to incubators, accelerators, venture capital, technology companies, biotech, and pharmaceutical companies. Additional relevant stakeholders to the African continent included NGOs (e.g., Clinton Foundation, ONE Campaign, United National Development Program) and public health agencies (e.g., Nigerian Centre for Disease Control (CDC)).

Track themes were sourced from both event partners and participant applications, amplifying the most pressing needs based on the timing of each event using a hybrid top-down and bottoms-up approach. Some track themes tackled deployment and coordination of COVID-19 testing, triaging, education and resources. Other focused on novel care delivery paradigms, health supply allocation, and healthcare workforce well-being and training. Some themes such as COVID-19 testing and misinformation crossed multiple events and necessitated different solutions depending on the local ecosystem they would be implemented in. BTP events centered on COVID-19 issues in the developed world such as the United States, while “Africa takes on COVID-19” focused exclusively on the emerging needs associated with COVID-19 in Africa. Although events were not directly linked,

Box 1. Hackathons and virtual event format

Hackathons are events that assemble participants to tackle problems within specific topic areas. Hackathons typically occur over multiple days, and allow for dedicated, focused time when teams brainstorm and develop solutions. The MIT Hacking Medicine health hackathon model combines participants from diverse backgrounds including science, engineering, medicine, design, payers, pharma, and policy. Participants form teams around specific problem statements, presented by individual participants or pre-defined by event organizers. Teams then characterize the problem, distilling it into distinct sub-problems. The team selects a single addressable problem and brainstorms potential solutions including hardware, software, or policy proposals. Solution development is guided by continuous feedback from mentors and organizers. Mentors have broad experience across academia, industry, government, global health, and entrepreneurship sectors. Finally, teams present their ideas to a judging panel. Team ideas are evaluated based on impact, innovation, implementation, feasibility, viability, and presentation. The COVID-19 hackathons replicated this in a virtual setting. Partnerships were established across academic, public, and private sectors. Participants applied via an online application form. Participants were selected based on application caliber, individuals’ alignment with event goals, and diversity of the participant pool. The entire event was run over Zoom and Slack, with opening and closing remarks delivered via webinars and individual team Zoom meeting rooms. Mentors joined team rooms as needed to provide guidance. Slack enabled asynchronous and synchronous communications where each team had a dedicated channel to interact with each other, mentors, and organizers. Participants formed teams through a problem pitching session. After 48 h of hacking, final pitch presentations were run in ten parallel tracks. Winning teams were announced in a closing webinar. Cash prizes ($500 USD) were awarded to four teams in each track. All teams were eligible to receive ongoing post-event support and engagement with organizers and partners of the MIT COVID-19 Challenge.

Fig. 1 Worldwide crowdsourced innovation. a, b Number of applicants per (a) country around the world and (b) state in the US for MIT COVID-19 Challenges. Gray color shading corresponds to no applicants from that country. c Fraction of teams continuing to work on their ideas post-event. Plots show team continuation for teams from recent virtual events and in-person events in 2016, 2017, and 2018 (GH, Grand Hack). Maps generated using Google GeoChart API under Creative Commons Attribution 4.0 License.
some participants, mentors, and partners overlapped across the
events. Each event had 10 tracks that participants could select to
join, with each track focused on a distinct topic area. Some
continuing teams include WePool which focused on smart
pooling of COVID-19 testing; SANIPACK which focused on the
development of personal N-95 UV-C sterilizers; and Birthing
Bridge which focused on coordination of pre-natal care to pre-
eclampsia patients in South African townships.

These programs achieve multiple objectives. Coordination of
innovation efforts across individuals and entities from around the
world break down social, cultural, and institutional barriers to
multi-disciplinary collaborations. Organized crowdsourcing
leverages diverse skillsets to produce highly viable concepts and
prototypes to quickly tackle problems. The flat structure across
participants, mentors, and partners, whereby intellectual property
is not compromised, facilitates rapid development, iteration, and
implementation.

Translation of these ideas requires an equal or greater emphasis
on post-hackathon activities. Follow-on engagement
opportunities were developed with partners to support teams to
further advance and implement their ideas. These included, but
were not limited to, a build-a-thon (a hackathon focused on
building software or hardware) in partnership with Amazon Web
Services (AWS), pitch sessions, mentorship, 1:1 dedicated check-
ins, and funding. Teams and partners were paired in a semi-
organic fashion to prioritize fit between team needs and available
partner resources. This approach balances the need to identify
and cultivate the most viable solutions with identifying the best
tools suited to execute.

The primary limitation to implementing ideas developed in
hackathons is team perseverance in continuing development of
their projects. This virtual platform enabled collaborative innova-
tion despite quarantine and social distancing constraints. Regular
follow-up surveys were sent to all participants prompting them to
report any updates on their projects. No incentive was given to
respond, and non-responders were assumed to have abandoned
their projects. Overall, more than 25% of all teams continue
working five weeks post-event. These results are only a few weeks

Table 1. Total number of applicants by country across three MIT COVID-19 Challenge events.

| Country                          | No. | Country               | No. | Country             | No. |
|----------------------------------|-----|-----------------------|-----|---------------------|-----|
| Afghanistan                      | 1   | Djibouti              | 1   | Libya               | 8   |
| Albania                          | 5   | Dominican Republic    | 3   | Macedonia           | 1   |
| Algeria                          | 18  | Ecuador               | 27  | Madagascar          | 3   |
| Angola                           | 1   | Egypt                 | 21  | Malawi              | 17  |
| Argentina                        | 12  | Eritrea               | 1   | Malaysia            | 13  |
| Armenia                          | 1   | Estonia               | 2   | Mauritania          | 1   |
| Australia                        | 49  | Eswatini (fmr. "Swaziland") | 2 | Mauritius          | 5   |
| Austria                          | 12  | Ethiopia              | 35  | Mexico              | 45  |
| Bahamas                          | 4   | Finland               | 4   | Mongolia            | 1   |
| Bangladesh                       | 15  | France                | 102 | Morocco             | 75  |
| Belgium                          | 9   | Germany               | 200 | Mozambique          | 13  |
| Benin                            | 2   | Ghana                 | 85  | Myanmar (formerly Burma) | 2 |
| Bhutan                           | 1   | Greece                | 8   | Namibia             | 3   |
| Bolivia                          | 5   | Guatemala             | 2   | Nepal               | 9   |
| Bosnia and Herzegovina           | 1   | Guinea                | 1   | Netherlands         | 45  |
| Botswana                         | 5   | Guinea-Bissau         | 1   | New Zealand         | 6   |
| Brazil                           | 125 | Honduras              | 2   | Niger               | 2   |
| Brunei                           | 1   | Hungary               | 6   | Nigeria             | 482 |
| Bulgaria                         | 1   | Iceland               | 1   | Norway              | 3   |
| Burkina Faso                     | 2   | India                 | 1169| Oman                | 1   |
| Cabo Verde                       | 1   | Indonesia             | 38  | Pakistan            | 50  |
| Cameroon                         | 40  | Iran                  | 11  | Palestine State     | 28  |
| Canada                           | 336 | Iraq                  | 1   | Peru                | 58  |
| Chile                            | 15  | Ireland               | 13  | Philippines         | 21  |
| China                            | 60  | Israel                | 16  | Poland              | 16  |
| Colombia                         | 26  | Italy                 | 84  | Portugal            | 18  |
| Congo (Congo-Brazzaville)        | 2   | Jamaica               | 2   | Qatar               | 1   |
| Costa Rica                       | 3   | Japan                 | 22  | Romania             | 11  |
| Côte D'Ivoire                    | 6   | Jordan                | 1   | Russia              | 9   |
| Croatia                          | 1   | Kazakhstan            | 14  | Rwanda              | 26  |
| Cuba                             | 1   | Kenya                 | 157 | Saudi Arabia        | 79  |
| Cyprus                           | 1   | Kuwait                | 1   | Senegal             | 9   |
| Czech Republic                   | 2   | Latvia                | 2   | Sierra Leone        | 16  |
| Czechia (Czech Republic)         | 3   | Lebanon               | 14  | Singapore           | 80  |
| Democratic Republic of the Congo | 14  | Lesotho               | 1   | South Africa        | 141 |
| Denmark                          | 11  | Liberia               | 5   | South Korea         | 13  |
after the event, and it is likely that more teams will stop working on their projects as time progresses. However, this rate of continuing teams is demonstratively higher than that of similar in-person events (average of 19% two weeks post-event) (Fig. 1c). One possible rationale for higher continuation rate following virtual, rather than in-person, events could be that teams formed on a virtual basis start accustomed to working in a decentralized and asynchronous manner compared to in-person hackathons where live co-working is a prerequisite. A second contributing factor is the greater proportion of time participants had during the time of quarantine and lockdowns, with few competing demands such as work, school, or social activities. Team continuation is likely also enhanced due to ubiquitous impending urgency to tackle the ongoing pandemic. Engaging teams quickly post-event with sustained support from strategic partners likely also decreased the attrition rate of teams compared to prior in-person events.

This approach interweaves bottom-up innovations along the translation pipeline through key strategic partnerships. Critiques of hackathons argue they have limited economic impact, as a result of their short duration. However, they do allow for a rapid burst of context-specific solutions to be created and implemented for and by individual communities, addressing health inequity. By activating untapped potential, bottom-up or grassroots innovation is a vital complement to traditional top-down institutional and governmental initiatives. This crowdsourced approach to solutions has been shown to be effective across domains in new idea generation. Catalyzing entrepreneurship and lowering the barrier to entry from such initiatives can serve as an engine for economic growth, an issue of special importance given the economic downturn the pandemic has caused.

These programs will not necessarily yield a new vaccine or drug therapy and are not meant to replace traditional R&D undertaken by academia and industry. They do, however, enable interdisciplinary collaborations and empower a new population to tackle problems that the ever-changing world brings. These events teach individuals problem solving skills, entrepreneurship, collaborative teamwork, and communication skills while creating new communities of entrepreneurs with novel solutions and potential ventures. There is great need to not only continue to implement these types of programs but to develop more robust research methodologies to assess and optimize the role and effectiveness of grassroots innovation within the greater context of healthcare innovation. The world has a shared interest in overcoming this pandemic and its downstream effects, and everyone should be given the opportunity to play an active role.

**DATA AVAILABILITY**

All data is available from the authors upon reasonable request.

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**Table 2.** Number of applicants per discipline per event.

| Discipline/finance | BTP1 | Africa | BTP2 |
|--------------------|------|--------|------|
| Business/finance   | 589 (12.4%) | 361 (15.7%) | 271 (13.4%) |
| Data engineer/data scientist | 456 (9.6%) | 118 (5.1%) | 219 (10.8%) |
| Designer           | 367 (7.7%) | 103 (4.5%) | 128 (6.3%) |
| Engineer           | 987 (20.7%) | 382 (16.6%) | 376 (18.6%) |
| Patient/patient’s family | 10 (0.2%) | 9 (0.4%) | 13 (0.6%) |
| Clinician/provider | 464 (9.7%) | 316 (13.7%) | 243 (12.0%) |
| Scientist          | 661 (13.9%) | 283 (12.3%) | 310 (15.3%) |
| Software           | 741 (15.5%) | 334 (14.5%) | 357 (17.6%) |
| Media              | 64 (1.3%) | 61 (2.6%) | 46 (2.3%) |
| Other (Health policy/Law/regulatory) | 428 (9.0%) | 338 (14.7%) | 62 (3.1%) |
| Total              | 4767 | 2305 | 2025 |
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AUTHOR CONTRIBUTIONS
F.T.N. collected the data. F.T.N. and K.B.R. jointly analyzed the data and wrote the manuscript.

COMPETING INTERESTS
K.B.R. and F.T.N. are previous co-directors of M.I.T. Hacking Medicine. F.T.N. helped organize the virtual hackathons described here. The authors declare no other competing interests.

ADDITIONAL INFORMATION
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