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PERSPECTIVE

Developing Future Biologists: developmental biology for undergraduates from underserved communities

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ABSTRACT

Developing Future Biologists (DFB) is an inclusive, trainee-run organization that strives to excite and engage the next generation of biologists, regardless of race, gender or socioeconomic status, in the field of developmental biology. DFB offers a week-long course consisting of active lectures, hands-on laboratory sessions, and professional development opportunities through interactions with scientists from a variety of backgrounds and careers. A major goal of DFB is to propel undergraduate students from underserved communities to pursue biomedical research opportunities and advanced degrees in science. To achieve this goal, we provide DFB participants with continuing access to a diverse network of scientists that students can utilize to secure opportunities and foster success throughout multiple stages of their research careers. Here, we describe the flourishing DFB program at the University of Michigan to encourage other institutions to create their own DFB programs.

Beginnings of DFB: promoting developmental biology in Puerto Rico

Developing Future Biologists (DFB) was conceived in 2015 by Andrea Ramos, then a PhD candidate at the University of Michigan (UM), USA. Dr Ramos wished to provide hands-on research in developmental biology to students in Puerto Rico (PR) who lacked access to these opportunities. At the time, only three out of ten University of PR undergraduate campuses offered a regular developmental biology course. The founding DFB team included Dr Ramos and four other PhD candidates: Brandon Carpenter, David Lorberbaum, Justine Pinskey and Martha Echevarria Andino. They recruited UM faculty members – Benjamin Allen, Scott Barolo, Deneen Wellik and Deborah Gumucio – to help develop the inaugural course in Ponce, PR. For 2 years, DFB instructors traveled to Ponce to engage undergraduates in research and expose them to biology-related careers.

Relocating and expanding DFB

In 2017, the course moved to UM, with students from around the country, including a significant number from PR, traveling (at no cost to them) to experience research at a resource-rich institution. Hosting students at UM allowed DFB to offer instruction to more participants from a broader range of communities and expose them to state-of-the-art facilities and a more comprehensive curriculum. Students from PR now comprise ∼50% of course participants.

A trainee-led, hands-on short course in developmental biology

DFB structure

The mission of DFB is to provide students with fundamental instruction in core developmental biology concepts and to excite them about pursuing research opportunities in development and related fields. We developed a five-day short course consisting of interactive lectures, group discussions, hands-on laboratory sessions, professional development workshops, and trainee-led panels (Fig. 1). Each day starts with an active-learning session led by the DFB faculty on key developmental concepts such as ‘What is development?’, followed by hands-on lab sessions where students work with several developmental model systems (Fig. 2A). Using these model organisms, DFB participants apply what they learn in lectures. For example, after learning about developmental signaling pathways, students test the effects of pharmacological pathway inhibitors on zebrafish development.

Professional development workshops throughout the course provide guidance on preparing materials, including a curriculum vitae, and use panels to introduce students to post-baccalaureate research opportunities, graduate programs and STEM (science, technology, engineering and mathematics) careers. DFB students, instructors and faculty members share dinner and participate in social events to network outside of the laboratory. Our course model engages students who might be curious about developmental biology, but are unaware of, are unable to commit to, or have not been accepted into summer research programs.

To ensure low instructor-to-student ratios, DFB accepts about 25 students each year, prioritizing applications from students with backgrounds that are under-represented in STEM fields (Fig. 2B). DFB students have little or no prior research experience and come from institutions with relatively few research opportunities. We gauge student learning through tests and feedback. Although the lectures only scratch the surface of developmental biology concepts, 84% of students in 2021 improved on the post-course conceptual assessment by an average of 13%. The number of students ‘interested’ in developmental biology increased from 80% to 97%, and students ‘very familiar’ with STEM careers increased from 3 to 23 students (out of 34 total).

DFB instructors serve a 2-year term, with veteran instructors onboarding and training new instructors each year. DFB trainee instructors – not faculty – manage all aspects of the course, including: (1) designing and executing the lab sessions; (2) leading fundraising efforts (DFB costs ∼35,000 USD per year) from both internal and

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<table>
<tr><th>EST</th><th>Day 1, Monday, 6/21</th><th>Day 2, Tuesday, 6/22</th><th>Day 3, Wednesday 6/23</th><th>Day 4, Thursday, 6/24</th><th>Day 5, Friday, 6/25</th></tr>
<tr><td>9:00 AM</td><td rowspan="4">Instructor office hour
(60 min)</td><td rowspan="4">Instructor office hour
(60 min)
Scott Barolo, PhD
Offline assessment of day 1
Due by 10 AM</td><td rowspan="4">Instructor office hour
(60 min)
Ben Allen, PhD
Offline assessment of day 2
Due by 10 AM</td><td rowspan="4">Instructor office hour
(60 min)
Scott Barolo and Ben Allen
Offline assessment of day 3
Due by 10 AM</td><td rowspan="4">Instructor office hour
(60 min)
Laura Buttitta, PhD
Offline assessment of day 4
Due by 10 AM</td></tr>
<tr><td>9:15 AM</td></tr>
<tr><td>9:30 AM</td></tr>
<tr><td>9:45 AM</td></tr>
<tr><td>10:00 AM</td><td rowspan="2">Welcome!
(30 min)</td><td>Small group discussion</td><td>Small group discussion</td><td>Small group discussion</td><td>Small group discussion</td></tr>
<tr><td>10:15 AM</td><td>Large group discussion</td><td>Large group discussion</td><td>Large group discussion</td><td>Large group discussion</td></tr>
<tr><td>10:30 AM</td><td rowspan="5">What is development?
(75 min)
Scott Barolo, PhD</td><td rowspan="5">Cell signaling
(75 min)
Ben Allen, PhD</td><td rowspan="5">Gene expression
(75 min)
Scott Barolo, PhD</td><td rowspan="5">Disease and development
(75 min)
Laura Buttitta, PhD</td><td rowspan="5">Panel 4: Careers in STEM
(75 min)</td></tr>
<tr><td>10:45 AM</td></tr>
<tr><td>11:00 AM</td></tr>
<tr><td>11:15 AM</td></tr>
<tr><td>11:30 AM</td></tr>
<tr><td>11:45 AM</td><td rowspan="3">Personal statement workshop
(60 min)</td><td>Student presentation 1</td><td>Student presentation 2</td><td>Student presentation 3</td><td>Student presentation 4</td></tr>
<tr><td>12:00 PM</td><td rowspan="2">Break
(45 min)</td><td rowspan="3">Break
(60 min)</td><td rowspan="2">Break
(45 min)</td><td rowspan="2">Break
(45 min)</td></tr>
<tr><td>12:15 PM</td></tr>
<tr><td>12:30 PM</td><td rowspan="3">Break
(45 min)</td><td rowspan="4">Panel 1: Postbac options
(75 min)</td><td rowspan="2">Careers workshop
(60 min)</td><td rowspan="6">Swagathon!!
(2+ h)</td></tr>
<tr><td>12:45 PM</td></tr>
<tr><td>1:00 PM</td><td rowspan="3">Organogenesis
(75 min)
Ben Allen, PhD</td></tr>
<tr><td>1:15 PM</td><td rowspan="5">Grad school, summer programs and more
(90 min)
Ben Allen, PhD</td></tr>
<tr><td>1:30 PM</td><td rowspan="3">Panel 3: DFB alumni
(75 min)</td></tr>
<tr><td>1:45 PM</td><td rowspan="4">Panel 2: Graduate and professional school
(75 min)</td></tr>
<tr><td>2:00 PM</td><td rowspan="3">CV workshop
(60 min)</td></tr>
<tr><td>2:15 PM</td></tr>
<tr><td>2:30 PM</td></tr>
<tr><td>2:45 PM</td><td rowspan="2">Prelab: Planarian regeneration
(30 min)</td><td rowspan="2">Prelab: Blood/immunology
(30 min)</td><td rowspan="2">Prelab: ImageJ
(30 min)</td><td rowspan="4">Farewell!</td></tr>
<tr><td>3:00 PM</td></tr>
<tr><td>3:15 PM</td><td>Prelab: PyMOL (15 min)</td></tr>
<tr><td>3:30 PM</td><td rowspan="2">Prelab: Zebrafish embryology
(30 min)</td><td rowspan="2">Prelab: Bioinformatics
(30 min)</td><td rowspan="2">Prelab: Gene expression: mouse embryos
(30 min)</td><td rowspan="2">Prelab: Disease and development using Drosophila
(30 min)</td></tr>
<tr><td>3:45 PM</td></tr>
<tr><td>4:00 PM</td><td rowspan="4">Instructor office hours
(2 h)
Office hours: Scott Barolo</td><td rowspan="6">Instructor office hours
(4 h)
**Bioinformatics demo:
4:30-5:30 PM
Office hours: Ben Allen
(5:00-7:00 PM)</td><td rowspan="3">Instructor office hours
(2 h)
Office hours: Ben Allen and Scott Barolo (4:00-6:00 PM)</td><td rowspan="6">Instructor office hours
(4 h)
Office hours: Laura Buttitta
(5:00-6:30 PM)</td><td rowspan="6"></td></tr>
<tr><td>4:30 PM</td></tr>
<tr><td>5:00 PM</td></tr>
<tr><td>5:30 PM</td><td rowspan="4">Game night - trivia!</td><td rowspan="3">Networking!</td></tr>
<tr><td>6:00 PM</td></tr>
<tr><td>6:30 PM</td></tr>
<tr><td>7:00 PM</td><td rowspan="2">Office hours: Ben Allen
(5:00-7:00 PM)</td></tr>
<tr><td>7:30 PM</td></tr>
</table>

Fig. 1. Daily schedule of the 2021 DFB virtual course. Each day began and ended with office hours held by DFB instructors and faculty. Small group discussions were led by two or three instructors with their designated groups (three or four students per group). Large group discussions included all instructors and students. Lectures were delivered by faculty members as indicated. Student groups were assigned a developmental disease prior to the course to present throughout the week. Lab introductions and workshops were given by various members of the instructor team. Not shown are the orientation sessions led by instructors prior to the course to review important program details and the pre-course assessment.

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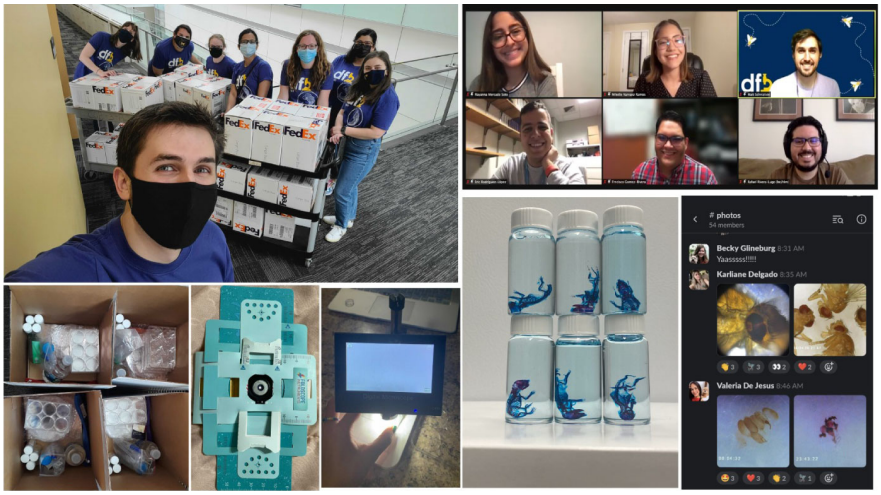
A DFB model organisms

B DFB short course (in person)

C DFB short course (virtual)



D Beyond DFB

Fig. 2. See next page for legend.

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Fig. 2. Summary of DFB offerings. (A) DFB model organisms. From left to right: X-gal-stained mid-gestation mouse embryo; embryonic day 18.5 mouse skeletal preparation; 4-day-old chicken embryo; live *Drosophila melanogaster*; live planarian that regenerated two heads (photos taken by students). (B) 2016 DFB in-person short course. Left: Students and instructors working together in the laboratory. Right: DFB 2016 cohort. (C) 2021 DFB virtual short course. Left: Preparation of lab kits, including lab supplies, microscopes and skeletal preps, sent to individual DFB participant homes. Top right: DFB alumni virtual panel. Bottom right: DFB slack messaging. (D) Impact beyond the DFB short course. Top left: A DFB alumna TA delivers a virtual mini-lecture. Bottom left: DFB summer fellows presenting posters at scientific conferences. Right: DFB faculty and student instructors interacting with DFB alumni at scientific conferences.

external sources; (3) coordinating logistics, including travel, housing, food, course space, equipment and reagents; and (4) engaging with student participants and invited guests.

Successfully implementing a hands-on course in a pandemic-induced virtual environment

Under COVID-19 restrictions in 2020, DFB instructors created a complete, virtual curriculum (Fig. 2C). Content was delivered via Zoom (https://zoom.us/), lecture recordings were shared on Google Drive (https://workspace.google.com/products/drive/), and communication occurred via Slack (https://slack.com/). Before the start of the course, students participated in small-group meetings and an orientation session, which increased student engagement. We have continued this practice after returning to in-person teaching. We also employed a Miro board (https://miro.com/) as a home base for the course and as a lab notebook and social directory for students. In 2021, Google Drive and Miro were replaced by Canvas (https://canvas.it.umich.edu/), which provided students with access to lecture slides, lab worksheets, the course handbook, and additional resources. We loaned computers so that all students could fully engage in the course and, recognizing that not all students had access to reliable internet connections or a private workspace, we limited synchronized class time to 4 hours a day, with all lectures, workshops and panels recorded. We still sought to provide a hands-on lab experience by providing comprehensive lab packages to all students (Fig. 2C; Box 1). Students received detailed protocols for experiments, were given pre-lab introductions by instructors, and were provided optional virtual office hours before and after synchronized class to ask questions and discuss technical issues.

An unexpected upside of the virtual format was being able to invite individuals from all over the US to participate in career and professional development sessions and panels, with diverse representation of both backgrounds and scientific careers, including DFB student and instructor alumni. These broader panels have been incorporated into the in-person DFB course. The virtual DFB course also allowed us to host more students (36 students versus 24 in-person) from a wider geographic range.

The virtual course did reduce opportunities for DFB instructors to connect with students because we could not network over meals or between events. To encourage students to form connections with each other and with the DFB instructors, we included three virtual social events, including a game night, and ended the course with a trivia competition (‘DFB Swagathon’) where student teams answered course-related questions to win prizes.

Expanding the impact of DFB

Initially, DFB focused on providing an intensive week-long short course, with limited interactions with student participants after completion. However, adapting the course to a virtual format highlighted how we could better engage with and support DFB alumni through long-term mentoring. Cognizant that some DFB student alumni have graduated, we wanted to provide accessible opportunities for alumni at any stage, including new training and professional development opportunities.

DFB trainee instructors created two new opportunities to engage alumni: (1) DFB teaching assistant (TA) positions, and (2) DFB student alumni summer research fellowships. TAs work with trainee instructors to plan and execute the 5-day course, but also work alongside faculty to co-teach mini-lectures. DFB summer research fellows conduct research directly with a DFB instructor for 8 weeks and present their research to instructors and peers at the end of their fellowship. These training opportunities are fully funded by DFB, including travel costs, housing costs and a stipend, allowing student alumni to gain teaching or research experiences that strengthen graduate school applications.

DFB has provided more than 20 travel awards to alumni to attend virtual scientific conferences (Fig. 2D). We continue to engage alumni through a ‘Monthly News Email’, with links to other virtual professional development opportunities. DFB hosted a Virtual Research Symposium to connect student alumni to UM faculty researchers and summer research programs. In addition to faculty short talks, three DFB summer research fellows presented their research projects at the symposium. An enduring lesson of the pandemic is that continued and regular interactions are necessary to maintain student engagement. Thus, a future goal of DFB is to establish a series of DFB workshops, available to all DFB student alumni, covering topics such as writing a compelling personal statement and an effective academic statement of purpose for graduate school applications.

DFB student success

The DFB short course engages undergraduates in hands-on research and introduces them to STEM careers. Since its inception, DFB has trained over 200 undergraduate students, most of whom had little to no research experience. Most DFB student alumni have pursued

Box 1. Virtual course laboratory sessions

We approached the lab component in two ways. First, we included virtual lab simulations through Labster (https://www.labster.com/) for complex lab sessions such as chicken embryo windowing, *Caenorhabditis elegans* signal transduction and genetics, and axolotl regeneration. We also incorporated dry lab sessions that introduced students to fundamental bioinformatic approaches, including the use of R and PyMOL and a session using ImageJ (https://imagej.nih.gov/ij/index.html) to count cells.

Second, for a true hands-on ‘wet’ lab experience, we shipped custom DFB at-home lab kits that included:

1. two portable microscopes [a foldscope (Cybulski et al., 2014) and a USB-powered microscope];
2. live *Drosophila melanogaster* (Fig. 2A) with tools necessary to perform ovary and intestinal dissections;
3. live planaria with tools to observe regeneration following manipulation (Fig. 2A);
4. blood slides to visualize immune cells and normal versus diseased (sickle cell) red blood cells;
5. fixed zebrafish embryos treated with or without teratogens to identify stages of development and compare the developmental effects of various chemicals;
6. X-gal-stained mouse embryos to understand mouse embryo development and identify an ‘unknown’ gene (*Shh*, *Hhip*, *Ptch1*) based on gene expression patterns (Fig. 2A);
7. mouse skeletal preparations to compare morphological differences in limb structures (Fig. 2A).

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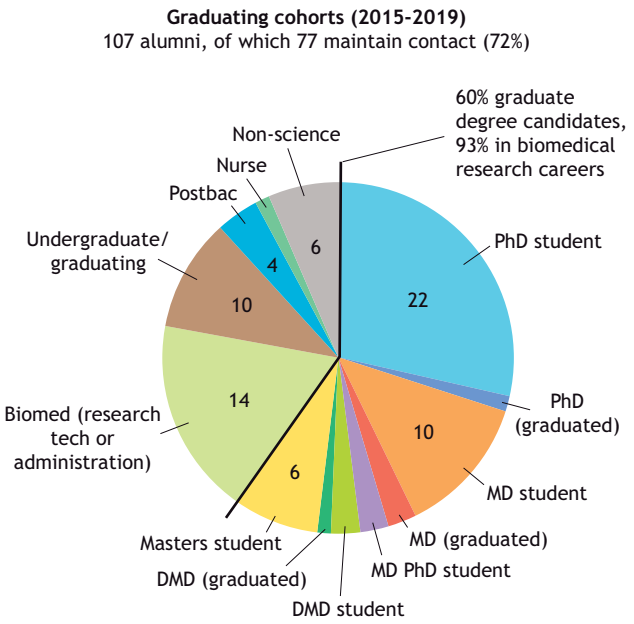

Fig. 3. 2015-2019 DFB student alumni careers. Alumni from the first five DFB cohorts were contacted, as these students had likely earned their bachelor's degrees by the time of the survey. Of the 77 alumni that responded, the majority (93%) participate in biomedical research careers, and more than half (60%) are pursing STEM graduate studies. DMD, Doctor of Medicine in Dentistry; MD, Doctor of Medicine.

summer research opportunities and/or post-baccalaureate research training or are currently in STEM graduate training. DFB alumni have also entered medical school, dental school or direct employment in science-related fields following the completion of their Bachelor's degree (Fig. 3).

Moving the course to Michigan facilitated interactions between DFB participants and UM research programs, including the University of Michigan Postbaccalaureate Research Education Program (UM PREP; https://medicine.umich.edu/medschool/education/non-degree-programs/postbac-research-education-program-um-prep), Pathways Masters Program (https://lsa.umich.edu/mcdb/graduate-students/pathway-masters-program.html), PhD Program in Biomedical Sciences (PIBS; https://medicine.umich.edu/medschool/education/phd-programs/about-pibs) and Summer Research Opportunity Program (SROP; https://rackham.umich.edu/rackham-life/diversity-equity-and-inclusion/srop/). These networking opportunities, including meetings with program directors and current students, informed DFB students about these programs and their application processes and requirements. DFB alumni have been accepted into all of the aforementioned programs. DFB itself established a summer research fellowship that trained one student in 2019, two students in 2021 and three in 2022. DFB participation has made under-represented students more aware of summer and post-baccalaureate research programs at UM. Enrollment of DFB students in these and similar programs has aided their admission to leading PhD programs around the country.

DFB instructor success

The heart of DFB is its team of graduate and post-doctoral instructors. DFB has recruited trainee instructors from over 30 labs, representing 13 departments/programs at UM. This instructor network provides DFB participants (past, present and future) with access to scientists in various disciplines and career paths. Through networking with instructor alumni, DFB participants receive valuable, discipline-specific input on achieving their career goals, as well as access to future career development opportunities.

Importantly, DFB trainee instructors also benefit from their participation in this course, gaining experience in leadership, administration and teaching from designing and operating the course and building professional connections and mentoring relationships with their peers. As DFB enters its 9th year, DFB student participants have become course instructors, and five DFB trainee instructors have become faculty members, where they can initiate similar programs at their own institutions.

Conclusion

DFB started from a simple idea: to provide students with fundamental instruction in core concepts of developmental biology and excite them about pursuing opportunities in biomedical research. Since then, DFB has expanded to an institutionally supported program that is constantly evolving, improving, and affecting change in communities across the US. We have coordinated with other programs at UM to increase the number of historically excluded students in science and expanded DFB beyond a 5-day course to include training opportunities for DFB alumni. Moving to a virtual environment in 2020 provided DFB instructors with a challenge, but also led to new opportunities that have continued in the return to in-person instruction. While we continue to grow DFB at the University of Michigan, we hope that this report inspires others to start similar programs at other institutions. Furthermore, this structure can be applied to many other STEM fields. Those interested in starting a similar program can contact us, see sample protocols, and learn more at contactDFB@umich.edu and https://www.developingfuturebiologists.com.

Acknowledgements

The Biology department and administrative personnel at UPR Ponce were instrumental in planning and implementing the Ponce courses. We particularly thank Dr Edu Suarez for continued support of DFB. Many units at the University of Michigan have generously supported our efforts (see Funding section). Additionally, we thank the previous DFB instructors who helped build DFB into what it is today. For further assessments of the course's effectiveness, see Pinskey et al., 2018 preprint. Lastly, we would like to thank the students, who arrived with excitement and curiosity, and who continue to use DFB to build their STEM careers.

Competing interests

The authors declare no competing or financial interests.

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