Integrative and Comparative Biology

Integrative and Comparative Biology, volume 63, number 6, pp. 1543–1549
https://doi.org/10.1093/icb/icad035

Society for Integrative and Comparative Biology

SYMPOSIUM

Common Interests Without Common Expertise: Reflections on Early-career Experiences in Cross-Disciplinary Research

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From the symposium "Large-scale biological phenomena arising from small-scale biophysical processes" presented at the annual meeting of the Society for Integrative and Comparative Biology virtual annual meeting, January 16–March 31, 2023.

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Synopsis Cross-disciplinary research enables us to tackle complex problems that require expertise from different fields. Such collaborations involve researchers who have different perspectives, communication styles, and knowledge bases, and can produce results far greater than the sum of their parts. However, in an era of increasing scientific specialization, there exist many barriers for students and early-career researchers (ECRs) interested in training and undertaking interdisciplinary research endeavors. This perspective examines the challenges that students and ECRs perceive and experience in cross-disciplinary work and proposes pathways to create more inclusive and welcoming research environments. This work emerges from a National Science Foundation (NSF)-funded workshop held during the Society for Integrative and Comparative Biology (SICB) Annual Meeting in January 2023 in Austin, TX. The workshop brought together seasoned interdisciplinary scientists with undergraduate and graduate students to identify and discuss perceived challenges through small group discussions and experience sharing. Through summarizing a range of student concerns about embarking on careers as interdisciplinary scientists and identifying ways to dismantle institutional and lab management-level barriers, we aim to promote an inclusive and collaborative problem-solving environment for scientists of all experience levels.

Introduction

As scientific problems become increasingly complex, interdisciplinary research correspondingly becomes increasingly important. Collaborations that successfully bring together researchers with diverse backgrounds and expertise can lead to new discoveries, new approaches, and new methodologies that would be difficult to achieve in single-discipline research programs (Metzger and Zare 1999; Naiman 1999; National Academy of Sciences 2005). Many scientific funding agencies and high-impact journals additionally consider multi-pronged approaches essential for funding and publication success (Rhoten and Parker 2004). Despite the potential of cross-discipline perspectives for producing ground-breaking and high-impact research, graduate students and other early-career researchers (ECRs) face many challenges when beginning cross-disciplinary research programs (Pannell et al. 2019).

In this perspective piece, we discuss some of the challenges faced by cross-disciplinary scientists across a range of experience levels, starting with student initiation into cross-disciplinary research projects. We draw on insights from a roundtable discussion in a cross-discipline symposium ("Large-scale biological phenomena arising from small-scale biophysical processes") and a lunch workshop ("Scientists Crossing: Getting involved in cross-disciplinary research") held during the Society for Integrative and Comparative Biology (SICB) Annual Meeting in January 2023 in Austin, TX. The workshop brought together interdisciplinary scientists and interested students to discuss the perceived challenges of interdisciplinary research from the student perspective. In total, 45 (13 undergraduate students, 13 graduate students, 2 postdocs, 3 faculty, 4 non-academic knowledge workers, and 10 unspecified) attendees participated in student-led small group

Advance Access publication May 22, 2023

discussions. Of the participants, 24 identified as biologists, 5 as engineers, 3 as physicists/mathematicians, and 8 as "other." The discussions followed the Carousel Feedback Cooperative Learning model developed by Kagan and Kagan (2009). Under this model, participants are divided into small groups and circulate the room at timed intervals. They visit individual stations (large paper sheets) with written prompts and discuss within their group which ideas they will add, along with constructive feedback to earlier responses. After visiting each station, the groups reassemble to collectively discuss responses. This model was ideal for our workshop as it permitted the active engagement of all participants and permitted participants to reflect on the responses of their peers.

Participants discussed barriers and potential solutions (to said barriers) in their experiences with cross-disciplinary science, guided by the following prompts:

(1) How does one prepare students or oneself to engage in research that does not fall into one discipline? Does one need to be a "jack of all trades?"
(2) How does one build and manage a diverse and inclusive research team? How does one provide a common research language? and
(3) What are strategies to solicit funding for research questions that are not included in canonical silos?

The primary goals of this piece are to present some challenges that students and ECRs face when pursuing interdisciplinary research. While we center the perspective of these early scientific career stages, it is important to acknowledge that many of these challenges were echoed by more senior researchers throughout our symposium. These shared challenges point to pervasive issues that impact cross-disciplinary researchers throughout their careers, which makes it crucial to address these barriers as early as possible. As such, we propose ways in which these identified barriers can be addressed or mitigated. We break these proposed solutions down, first into structural changes at the institutional level, and second into changes at the management level of individual research groups, with proposed steps that individual primary investigators (PIs) can take to create inclusive, welcoming environments that can produce the next generation of cross-disciplinary researchers. Finally, we highlight the importance of student self-advocacy for the creation of these collaborative environments. Ultimately, we hope to highlight the tangible benefits of culturing a hospitable environment where students and ECRs can thrive while addressing challenging but rewarding cross-disciplinary problems.

Challenges for new cross-disciplinary researchers

Graduate students and ECRs face numerous challenges when trying to engage in cross-disciplinary research for the first time. We also found through our discussions that these challenges can be shared by more seasoned research scientists, thus highlighting systemic barriers that impede the progress of cross-disciplinary research across a range of experience levels. These challenges include (1) a lack of structured preparation, (2) the psychological burden of being an "outgroup," and (3) finding a common language between researchers.

Lack of structured preparation

For students in training, exposure to cross-disciplinary work is often limited within their programs of study, with little flexibility to broaden their learning outside of their discipline. Despite the increasing trend of interdisciplinary undergraduate degree programs (Brint et al. 2009), most interdisciplinary experiences are limited to summer research experiences with few links to undergraduate coursework (Beck et al. 2007; Tripp et al. 2020). Participants expressed insecurity about moving from one specific discipline to another or into an interdisciplinary program, as they felt they lacked adequate preparation. While several interdisciplinary graduate training programs were mentioned in the workshop and have been reviewed in the literature (Graybill et al. 2006; McKee et al. 2021), participants found it challenging to identify clear paths to becoming interdisciplinary researchers after receiving their terminal degree. Many saw it as a challenge to fit their research interests and aspirations back into the traditional departmental structure and confines to land faculty positions; some believed industry jobs relatively easier to obtain in these circumstances (Nugent and Kulkarni 2013). Our workshop participants were self-selected and expressed interest in cross-disciplinary work. It is plausible that other students, especially from underrepresented minority groups, are not aware of such career path due to a lack of role models (Lawner et al. 2019; Zhang et al. 2023) or career counseling (Cromley et al. 2016).

Our roundtable discussion with the symposium speakers, who are more seasoned researchers, indicated that their journeys culminating in thriving cross-disciplinary research programs were largely directed by serendipity or driven by some original question of interest that led them in "strange" new directions. This roundtable comprised of four postdoctoral researchers, three assistant professors, two tenured professors, and two scientists working in industry. These researchers tended to follow circuitous career paths, bouncing around from department to department before they

establish themselves permanently. As one more senior workshop participant noted dryly: "Perhaps a drunken walk isn't the best way to train a new generation of interdisciplinary scientists." Even once established, cross-disciplinary researchers can be unusual in their more traditionally siloed departments. As they work on very different problems than their colleagues, it becomes a challenge for students interested in cross-disciplinary work to identify prospective mentors or seek additional mentors after joining a specific lab. Ultimately, this lack of mentorship can lead to students feeling isolated and unsupported in their research goals.

Psychological burden of being the "outgroup"

A considerable proportion of our workshop participants experience high levels of anxiety and "imposter syndrome" (Sills et al. 2020), and deal with feelings of loneliness or perceived exclusion. One participant expressed how they feel during a group meeting: "I know things other members of the group don't, and yet I do not understand what they are talking about. . . I can't contribute and I feel very discouraged." More experienced faculty shared similar sentiments, describing themselves in such terms as "to those in the biology department, I am the physics guy; but to those in the physics department, I am the frog person working in the biology building." The out-of-place feeling appears to persist beyond the early years as a cross-disciplinary scientist. Participants shared with us that the workshop was helpful, in that it highlighted the ubiquity of these feelings of isolation. This perceived lack of support risks a strong self-selection bias in those who embark in cross-disciplinary research (Swafford and Anderson 2020; Toyokawa and DeWald 2020; Faniko et al. 2022), leaving only the most intrinsically confident students to forge ahead.

The challenge in finding a common language

Setting a common language and set of expectations in a group of diverse backgrounds can also be a significant challenge (Bracken and Oughton 2006; Pannell et al. 2019; Kaufmann et al. 2020). As an example, in the ice breaker of our workshop, participants were asked to introduce themselves and name their favorite small and large organisms. What became clear over the course of the ice breaker activity was that a group of 45 biologists, physicists, mathematicians, and engineers did not have a common definition of what constituted "small" and "large": to some, a small organism was an *Escherichia coli* cell; to others, a small organism was a red-tailed squirrel. The purpose of the exercise was to highlight unforeseen difficulties in communication and potential pitfalls when working with a large and diverse group of researchers. Overall, we argue that these challenges must be addressed to promote cross-disciplinary research and create a more inclusive and collaborative environment for early-career scientists.

What can we do to improve early-career experiences in cross-disciplinary work?

Workshop participants were asked to formulate strategies that would mitigate or remove their perceived barriers to effective cross-disciplinary research. We found that these tended to fall into (1) structural (institution-level) changes, (2) research group-level strategies (to be implemented by PIs), and (3) student self-advocacy strategies.

Structural strategies at the institution-level

To remove systemic barriers and promote student entry into cross-disciplinary research, institutions must look for opportunities for faculty of different disciplines and graduate students to interact, in both formal and informal settings. A commitment to structural change, for instance, through the restructuring and/or evolution of departments, or the establishment of research centers, can work to remove discipline barriers. This approach has shown some promise in increasing research productivity and funding (Leahey and Barringer 2020). The challenges of establishing, maintaining, and assessing these centers are reviewed elsewhere (Glied et al. 2007; Boden and Borrego 2011). To our student and ERC participants, such interdisciplinary institutes or programs are often perceived merely as seminar organizers or names to put on funding applications (i.e., cost-sharing centers). Whether this perception is accurate remains challenging to gauge. Some literature suggests that small and multi-disciplinary departments or centers produce more cross-disciplinary student theses (Mitrany and Stokols 2005) and report higher student satisfaction (Newswander and Borrego 2009). Nevertheless, large-scale studies investigating the impact/benefits of interdisciplinary center creation for students and ECRs remain rare and should be an avenue of further study (Leahey and Barringer 2020).

To better foster supportive environments for students and ECRs, these centers can create opportunities for meaningful cross-disciplinary interactions through informal gatherings. Departmental or group coffee/beer hours set aside time for unstructured conversations with colleagues [Suzuki et al. (2012), for instance, describe how a coffee break discussion led to a 30 year research program]. These centers can also act as the catalyst for special interest meet-up groups/communities of practice (Wenger 1998). Communities of practice refer to groups of people who share an interest and who engage in co-learning through regular interaction.

Such groups in the scientific community have demonstrated the need for regular meeting times (Daniell 2006), organic formation mechanisms, and space for observers (Cundill et al. 2015). Research centers can thus foster these communities by way of regular seminars, coffee/beer hours, and setting aside physical space to promote meaningful interactions, or as O'Meeara and Culpepper (2020) call them, "collisions." We believe such actions by research centers could do much to combat the sense of isolation that many cross-disciplinary researchers experience.

For more advanced cross-disciplinary researchers, the institutional barriers may stem from their poor fit in any traditional discipline silo. Cluster hiring has been proposed as a strategy to help us better meet grand challenges and diversify faculty (Freeman 2019). However, without proper organizational support, collaborations are limited and cluster hires find themselves ultimately more aligned with traditional academic units instead of the cluster (Bloom et al. 2020). Additionally, cross-disciplinary researchers are often cross-listed between two departments, and as such, institutions must clearly define tenure and promotion expectations for these researchers, ensuring that cross-listing does not result in doubled expectations (Klein and Falk-Krzesinski 2017; Arnold et al. 2021). The effect of such doubled expectations on tenure-track faculty is perhaps more obvious, but poor departmental fit affects students as well. Cross-disciplinary students report greater satisfaction with their programs when their advisors are situated in interdisciplinary centers, rather than in traditional departments (Newswander and Borrego 2009). Cross-disciplinary students, particularly those situated in departments outside their core undergraduate area, may also struggle with evaluation structures in place for graduate students. In these cases, traditional discipline-based comprehensive evaluations may be removed (Gardner 2011) but how to structure PhD programs in the absence of these traditional comprehensive exams remains an ongoing debate within many departments.

Interdisciplinary research is encouraged across funding agencies in the United States and internationally (Rhoten and Parker 2004; National Academy of Sciences 2005; Sá 2008). Both the National Science Foundation (NSF) and the National Institute of Health (NIH) provide funding for cross-disciplinary research programs, centers of interest, and training. Other private foundations such as the Gordon and Betty Moore, Sloan, and John Templeton Foundations also provide support for theme-based, cross-disciplinary research (Aldrich 2014). Nevertheless, workshop participants commented on the seeming lack of transparency of the review process and the challenges inherent in meeting the expectations of discipline-focused reviewers (i.e., battling "the favoritism of the familiar") (Porter and Rossini 1985; Bromham et al. 2016). Unfortunately, the perceived issues with review transparency are similar to those articulated by Perper et al. (1989), which suggests that not much progress has been made in this area. Researchers submit more risk-averse proposals when they believe that reviewers view risky proposals as unlikely to generate surprising results (Gross and Bergstrom 2021). To encourage innovative approaches that combine expertise from multiple fields, continued and targeted outreach from funding agencies to the scientific community is needed. Increased visibility through virtual office hours, conference exhibition booths and one-on-one meetings with Program Directors at professional meetings may help demystify the process, particularly to students and ECRs. Some explicitly cross-disciplinary funding agencies such as the Human Frontier Science Program (HFSP) have led the way in this respect, issuing direct guidelines on what constitutes "interdisciplinarity" and "high-risk." HFSP further dedicates their companion journal to the publication of solely cross-disciplinary research (Bisby 2007). Senior workshop and roundtable participants also encouraged cross-disciplinary colleagues to volunteer as reviewers and grant panelists and to review proposals based on a thoughtful and open-minded evaluation of the project's potential. Open-minded evaluation has the potential to reward proposals, which challenge previous community understanding (Gross and Bergstrom 2021), and can lead to more constructive, actionable feedback (Aleksic et al. 2014; Kelly et al. 2014; Mavrogenis et al. 2020).

Strategies at the research group management level

To foster healthy environments where cross-disciplinary research can thrive, workshop participants suggested several steps, which can be accomplished in individual research groups. First and foremost, it is crucial for PIs to build safe environments with empathy and growth mindsets (Seaton 2018; Canning et al. 2019). The suggestions in this section identify areas for PIs to work on within their groups. However, we also recognize that fostering inclusive and welcoming research environments requires reflection and on-going work (Pannell et al. 2019; Emery et al. 2021).

A safe environment for cross-disciplinary research requires setting a group culture and norms that are conducive to open and honest exchanges of ideas, prioritize clarity and increased understanding, and allow for vulnerability. In this vein, workshop participants candidly discussed how their anxiety about their perceived lack of knowledge often prevents them from asking questions even of their lab mates or collaborators in informal settings. Given that interactions with research

mentors shape student self-efficacy and self-belief (Lechuga 2014; Robnett et al. 2018), our first suggestion is for PIs to lead by example and demonstrate willingness to ask questions themselves in one-on-one settings with students, in group meetings, and in seminars. The PI's role in modeling and mentoring their students in the "no stupid questions" mindset is crucial. Similarly, open discussions about imposter syndrome can help normalize these shared feelings and help students (Sills et al. 2020; Woolston 2021) and ECRs identify strategies to cope with this challenge (Abdelaal 2020).

Mindful recruitment can help attract students from diverse training backgrounds. Mindfulness here refers to crafting inviting advertisements, advertising in accessible platforms, and keeping biases in check (Ahmad et al. 2019). Researchers with applied research questions (e.g., biomedical informatics, bioinspired robotics, conservation management) may find it natural to recruit from multiple disciplines as core undergraduate knowledge may translate readily between some fields (e.g., computer science to bioinformatics; Beck et al. 2007). In other cases, PIs may hesitate to take on a student from a different background if they feel they cannot offer adequate support. We suggest identifying other faculty as prospective collaborators and co-supervisors for their students from non-traditional backgrounds. Interdisciplinary research centers within institutions, research coordination networks, and professional societies are fruitful venues to develop these working relationships. This approach models another good behavior to students who wish to engage in cross-disciplinary research—recognizing the bounds of one's own expertise and knowing when to ask for help.

Retention of talent requires both common goals and a common language for effective communication. One strategy is to develop a jargon-free, non-technical communication style where possible and include a pedagogical slant in group meeting presentations (Bracken and Oughton 2006; Leigh and Brown 2021). The default assumption of background knowledge on the part of the audience should be challenged whenever possible, to promote good practice in general scientific communication. Finally, the PI can cultivate shared, ever-evolving research group documents. In these, students become responsible for writing and maintaining descriptions of equipment, protocols, methodologies, research aims, or project results in ways that are clear to both expert and more general audiences. Such "living documents" help maintain institutional knowledge within groups but largely help students develop good habits in their general scientific communication. Maintaining such documents may additionally benefit the group culture as it emphasizes how the group relies on cooperation and the collective expertise of group members. This can also be a student-led initiative within a group (see the "Student self-advocacy strategies" section below).

To promote open-mindedness and a multi-viewed perspective, project and research goals can be canvassed at a group level in roundtable discussions (Palmer 1999). The PI plays a critical role in such discussions by setting clear expectations for respectful dialogue, moderating discussion to ensure diverse perspectives are heard, and by ensuring that all group members are aware of the expertise and strengths of the other members [see for instance Handelsman et al. (2007)]. The PI is uniquely poised to encourage and foster collaborative discussion between students with different expertise but shared interests, as they have the most holistic understanding of their group members' strengths. Such roundtable discussions can be group-based or involve multiple research groups simultaneously to foster new links and collaborations between groups.

Student self-advocacy

Students in the workshop acknowledged that self-advocacy was required to overcome the barriers that impede entry into cross-disciplinary research. Students shared their own broad strategies: staying open-minded and being kind to themselves, recognizing that "it's okay to ask questions," and maintaining enthusiasm for learning about new disciplines and methodologies. Students can additionally work with their PIs to put in place good communication strategies and producing living documents to be commonly edited by the research group. While these living documents can be an exercise in good communication and collaboration practices implemented by the PI, they can also readily be student-led initiatives, as was the case in more than one research group present at the workshop. Students also discussed how they combated feelings of isolation and imposter syndrome with social media use. Spreading their work by social media additionally helps students build connections, foster future collaborations, and get direct feedback on their work (Lupton 2014; Collins et al. 2016). However, social media can also induce feelings of inadequacy and anxiety in students and ECRs when they observe the curated experiences of other researchers (Guillaume et al. 2019), and as such it should be used thoughtfully. Finally, students in the workshop continually returned to the importance of good scientific communication skills for engaging in functional collaborations and funding solicitations. From the student and ECR perspective, effective communication is frequently required to explain or justify work to discipline-focused departments, conference audiences, and grant reviewers. Workshops on public sci-

ence outreach, elevator pitches, the "three minute thesis," and other communication strategies were highlighted as important tools that students could seek out to improve their confidence and capacity to engage with scientists in other disciplines, as well as the broader scientific community and the general public (Brownell et al. 2013).

Final remarks

Engaging students in cross-disciplinary scientific research is a vital pursuit that requires a buy-in from students, faculty, and institutions. Many challenges that new researchers face when pursuing interdisciplinary work are complex and stem from systemic issues that require institutional changes. Our workshop participants additionally provided valuable insights into barriers that can be addressed at the research group level, through a combination of student self-advocacy and mentor support. Our main, and perhaps unsurprising, conclusion from this workshop is that institutions, PIs, and students alike must work together to advocate for collaboration and inclusivity, culturing a hospitable and welcoming environment where individuals from different backgrounds can work together to find innovative solutions to complex scientific problems.

Funding

Both the symposium and the workshop were generously supported by the National Science Foundation (NSF-233770) and the Company of Biologists (EA630).

Acknowledgments

We thank all our workshop and symposium participants for their thoughtful discussions. We additionally thank J. Gonzales and B. Jorgensen for documenting and transcribing the workshop discussion.

Conflict of interest

The authors declare that there is no conflict of interest.

Data availability statement

The workshop and roundtable participants did not give written consent for their data to be shared publicly, supporting data therefore is not available.

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