# Preparing Graduate Students and Undergraduates for Interdisciplinary Research

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*Colleges and universities need to provide students with training and experience in (a) interdisciplinary research, (b) the fuzzy areas of responsible conduct of research, and (c) the mentor–mentee relationship. We developed workshops that combine the three content objectives—interdisciplinary research, responsible conduct of research, and mentor–mentee relationship, therefore promoting explicit reflection on how these topics relate. To provide students with the same framework for their subsequent research collaboration, we conducted the workshops in parallel for the graduate mentors and their undergraduate mentees. For each of the sessions in the workshop for the graduate mentors, the graduate students reported overall gains in their skill levels of 21%, 24%, and 23% for interdisciplinary research, responsible conduct of research, and mentoring skills, respectively. For each of the sessions in the undergraduate workshop, the undergraduates reported overall gains in their skill levels of 33%, 27%, and 31% for interdisciplinary research, responsible conduct of research, and mentee skills, respectively.*

*Keywords: interdisciplinary research, responsible conduct of research, mentor–mentee relationship, undergraduate STEM education, graduate student training*

**Federal agencies, national educational and research** organizations, and business and industry are promoting interdisciplinary research by teams of researchers because it is via such teams that the most challenging economic, health, environmental, and other societal issues can be addressed (NAS-NAE-IM 2004, IM-NAS-NAE 2007, Lyall et al. 2011). These issues are often dubbed "wicked problems," because they are so difficult to define and resolve; therefore, no one discipline can adequately address them (Conklin 2006). Therefore, career success for future scientists will depend increasingly on the ability to conduct research within interdisciplinary teams. Believing there are advantages to early training, we set up an interdisciplinary research program for undergraduate programs across the science, technology, engineering, and mathematics (STEM) disciplines. In this program, graduate students were to be the direct mentors for the undergraduate researchers.

We knew that interdisciplinary research carries inherent risks that arise from conflicting research models and norms of different disciplines (Repko 2008a). The research on the topic of interdisciplinary research indicates that students can benefit by learning about the theory and process of interdisciplinary research; such understanding minimizes the risks and in turn facilitates the development, design, management, and—therefore—success of interdisciplinary research (Repko 2008a, 2008b, Lyall and Meagher 2012). A key part of our student interdisciplinary research program was workshops that would prepare the novice undergraduates and especially their graduate mentors for interdisciplinary research. Although guided by faculty mentors, it often would be the graduate students who would be supervising the day-to-day work of the undergraduates. We felt that training should address the graduate and undergraduate students' readiness for collaboration. They should be able to recognize and work with various collaborative styles and behaviors; acknowledge differing perspectives of other team members; be familiar with the assumptions, epistemologies, and research methods across the disciplines involved; and know how to apply methods for creating common ground for researchers of all disciplines (Boix Mansilla and Dawes Duraising 2007, Lyall and Meagher 2008). We anticipated that engaging students in interactions with students in other STEM disciplines within the structured setting of the workshop would alleviate the anxiety of dealing with the actual complex problems of interdisciplinary research that they would soon encounter. Our workshop design also considered that students starting to work on an interdisciplinary research project may have difficulty determining how much breadth, and what kind of breadth they need to develop and when; and that they may have concerns about how to present

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their interdisciplinary research work to others and in the job market. As Lyall and Meagher (2012) pointed out, "effective interdisciplinary working does not 'simply happen'; it calls for greater reflection—and greater effort—by those involved." Accordingly, explicit interdisciplinary research training can facilitate that and even streamline the process (Wagner et al. 2012).

In addition to preparing students for interdisciplinary research, we believe it is important that students realize that different disciplines vary with regard to experimental design, data management and ownership, authorship on publications, and other aspects of responsible conduct of research. As federal agencies are requiring that universities provide explicit training in responsible conduct of research to students beyond just online training modules in the *do*s and *don't*s of working with hazardous materials and to certify that researchers have had substantive responsible conduct of research training, we designed the interdisciplinary research training workshops to include live responsible conduct of research training, with special reference to differences across disciplines as would be encountered in interdisciplinary research.

Furthermore, knowing that prior training of mentors increases retention of scientists-in-training at both the graduate and undergraduate levels (Dolan and Johnson 2009), the graduate students and undergraduates received parallel training as research mentors and mentees, respectively. Successful mentoring programs emphasize the need for training in how to communicate expectations and set goals in ways that develop and maintain a healthy and productive research partnership (Handelsman et al. 2005). Based on that finding, we designed our program with the aim of developing in both mentors and mentees, coordinated expectations both for their interdisciplinary research project and their mentor–mentee relationship, so they would be better able to achieve a good working relationship and to work out difficulties that might arise.

Knowing that self-efficacy, or a person's belief in his or her capabilities, can affect academic achievement and perseverance in a learning task (Trujillo and Tanner 2014), we began the students' interdisciplinary research experience with workshops that would introduce them ahead of time to the challenges that they would face, to give them tools to handle the challenges and build their self-confidence. Because this would be the first research experience for the undergraduates and the first research mentoring experience for many graduate students, our workshops also addressed responsible conduct of research and the mentor–mentee relationship in the context of interdisciplinary research. Here we report the structure—a workshop for the undergraduates and a parallel one for the graduate mentors—and used students' self-reporting to determine their gains in self-confidence. Our objectives for the outcomes of the workshop were that students could anticipate and recognize problem situations and, accordingly, exhibit enhanced self-efficacy.

## Methods

Our workshops are the instructional foundation for a structured 12-month interdisciplinary research experience for the students. Each interdisciplinary research team consists of a life science faculty member partnering with a faculty member from a physical science, mathematics, computer science, or engineering to design and oversee a project. Each faculty member nominates a graduate student from his or her laboratory, ranging from advanced master's to fifth-year doctoral students, to receive training in interdisciplinary research, responsible conduct of research, and mentorship, then to participate in a mentor internship in an interdisciplinary research project. Each interdisciplinary research faculty team selects two or three college science and engineering majors from a pool of applicants responding to a university-wide announcement that included descriptions of the proposed research projects and what they are expected to accomplish, such that each interdisciplinary research team has a life sciences major and other STEM major who will work together. Through four years, 107 junior and senior undergraduate students and 47 graduate mentors have participated in the program.

Our workshops consist of three sessions (interdisciplinary research, responsible conduct of research, and the mentor–mentee relationship) on three consecutive days at the outset of the program (table 1). Each session is about three hours, with the latter sessions encompassing lessons learned earlier. Prior reading assignments and preparation are required of the students. The workshop for graduate students emphasizes mentorship of undergraduate researchers and responsible conduct of research within an interdisciplinary team (see the supplemental material). It begins with the mentor–mentee session, so that the graduate students have that in mind as they participate in the interdisciplinary research and responsible conduct of research sessions. The workshop for undergraduates focuses on familiarizing them with what to expect as researchers in interdisciplinary STEM research, specifically in team collaboration, and how to maximize their chance of success by being responsible mentees (see the supplemental material). It begins with interdisciplinary research, followed by responsible conduct of research, and ends with the mentor–mentee session, so the undergraduates have in mind what being a mentee in an interdisciplinary research team project entails.

The interdisciplinary research module for the workshops is based on Allen Repko's (2008a) *Interdisciplinary Research: Process and Theory*. Repko's (2008a) textbook provides a process for comparing and discussing the differing perspectives, assumptions, epistemology, theory, concepts, and methods of disciplines, which is a crucial step in communicating effectively across disciplines. The five areas in any interdisciplinary research project—the research, system, theory, concepts, and methods—are mapped, akin to a concept map but aimed at answering questions about how to proceed. To further the training and engage the students, we use activities based on research problems gleaned from current events media, such as the projects funded by the

***Table 1. Twelve-month science, technology, engineering, and mathematics interdisciplinary research program for undergraduates.***

| | Assessments | | |
|---|---|---|---|
| **Program timeline** | **Undergraduates** | **Graduate student research mentors** | **Faculty members** |
| Late May, start of interdisciplinary research program year | Workshop (three 3-hour sessions), followed by self-reported gains in interdisciplinary research/responsible conduct of research/mentor–mentee "end of workshop" surveys | Workshop (three 3-hour sessions), followed by self-reported gains in interdisciplinary research/responsible conduct of research/mentor–mentee "end of workshop" surveys | |
| End of July | Surveys by email asked how workshops prepared them for research | Surveys by e-mail for evaluation of undergraduates mentees | Surveys by e-mail for evaluation of undergraduates mentees |
| Late April, end of interdisciplinary research program year | | Survey by email asked value of workshops for preparing them for this experience; essays reflecting on mentoring experience | |

*Note:* Each interdisciplinary research team had two faculty mentors from different disciplines, one or two graduate student research mentors nominated by those faculty, and two or three undergraduates majoring in different disciplines and representing the disciplines of the faculty. Some surveys were paper and others online, each with some questions for free-form answers.

Bill and Melinda Gates Foundation's Grand Challenges Explorations, which are aimed at world health problems and which typically require a broad interdisciplinary approach. We ask student teams to outline what they would need to know and accomplish, to develop a chewing gum to detect signs of malaria from saliva (Anonymous 2009). This kind of activity works especially well because it pushes the students to think beyond their own discipline and because students have diverse academic backgrounds, each team comes up with different approaches. Importantly, through discussion, students voice for themselves the value of working with people from other disciplines as they realize that they, by themselves, cannot accumulate enough expertise fast enough to solve the problem in a reasonable timeframe. To illustrate lessons learned from collaboration, we use famous interdisciplinary research examples, such as the story of the discovery of the structure of DNA. For instance, video clips are available on the Internet of James Watson and Francis Crick talking about how they worked together, especially how having an open mind is essential, how not being afraid to make mistakes is imperative, and how success hinges not so much on what you know but on learning to ask questions, regardless of how simple they might seem. Then students are asked to map the interdisciplinary research project that they will be working on, explain their maps to other teams, and reflect on difficulties they had. For instance, the Lyme disease epidemiology project linking biomedical anthropology, complex systems science, and ecology, collects ecological, spatial, human behavioral, and demographic data to construct a computational model to predict the risk of tick-borne disease infection in humans living in suburban areas. Our workshop activity asks students from diverse disciplines to draw on their different knowledge and experience to make plans for their interdisciplinary research project, therefore guiding them to determine collectively what they know, what they do not know, and what they need to find out.

Our responsible conduct of research module is based on one developed at the University of Oklahoma for university-wide training of graduate students, as described by Mumford and colleagues (Mumford and Antes 2008, Mumford et al. 2008, Kligyte et al. 2008). This module emphasizes understanding the rationale for ethical decisionmaking and, therefore, how to address the fuzzy areas of responsible conduct of research issues in any discipline. To lay the foundation for ethical decisionmaking, we discuss how it is human nature for the fight-or-flight response to kick in when a conflict arises (e.g., data ownership) and how this prevents us from making what in hindsight would be a better, less emotional response (Lehrer 2009). A key feature is recognizing problematic situations, questioning one's own judgment, dealing with emotions, anticipating consequences, analyzing personal motivations, considering others' perspectives, and seeking outside help. We use case studies as examples of what can go wrong when well-meaning people make poor, emotionally charged decisions (Kevles 1998). The case studies also illustrate the pitfalls of not making one's own expectations about collaboration clear and failing in one's own responsibilities in the mentor–mentee relationship; therefore, the case studies reinforce themes in the interdisciplinary research and mentorship modules. We present case studies as short video clips showing different versions of how a situation might play out (*http://ori.hhs.gov*). Student teams then create skits to depict a research-relevant situation going badly, followed by a version in which they correct the situation. Throughout this session the case studies address problems such as messy lab partners, poor documentation of data, misunderstandings over data ownership and authorship, and plagiarism. With the graduate students, we also emphasized the importance of setting expectations with their undergraduates.

We adapted a nationally recognized best-practices mentor-training module developed at the University of Wisconsin at

Madison for faculty and graduate students entitled "Entering mentoring" (Handelsman et al. 2005). As Thiry and Laursen (2011) pointed out, "Novice students needed clear expectations, guidelines, and orientation to their specific research project, while experienced students needed broader socialization in adopting the traits, habits, and temperament of scientific researchers" (p. 771). Our approach is to help both the mentor and the mentee understand these needs and how those change over time. We begin by asking students to define and contrast the roles of mentor and mentee. Students bring to the session their completed learning styles inventory, and then we discuss what they learned from that and the insight it gave them regarding their roles as mentor and mentee. We use the Felder–Soloman Index of Learning Styles, which is available free on the Internet along with interpretative materials, research reports and applications to college teaching (Felder and Silverman 1988, Soloman and Felder 2008). Again, we use freely available video clips of case studies particularly from Michigan State University's Graduate School, which describes a variety of situations that require conflict resolution (Klomparens et al. 2004). We emphasize how to recognize individual interests and common ground and, therefore, achieve mutually agreed on resolution. Then through a series of activities, the graduate students learn the elements of a good research project, how to set expectations, how to check their mentee's understanding, how to establish trust, what their mentee's responsibilities are, and what makes for an inspired mentor–mentee relationship. Because the undergraduate students are working in teams that include graduate students from a discipline different from their own, we modified available materials to include discussion of the mentor–mentee relationship across disciplines. Also, anticipating that fuzzy areas in responsible conduct of research issues can be messier in interdisciplinary research, our training modules encompass situations where underlying differences in discipline may lead to conflicting decisions. Finally, graduate students partner to create concept maps of their mentoring plans for work with undergraduate researchers, taking into account the developmental aspects of the mentor–mentee relationship and the undergraduates' readiness for research.

To assess students' perception of their gains in self-confidence from the workshops (table 1), which were given at the start of the 12-month program, we analyze paper surveys (see the supplemental material) at the end of each session of the workshops. At the end of the summer phase and the 12-month program, we obtained feedback from the undergraduates and graduate mentors after they experienced working together on their interdisciplinary research projects via online surveys that included free-form questions. At the end of the initial summer phase during which students did research full time, the undergraduates are asked in an online survey how well the workshop sessions prepared them for interdisciplinary research, responsible conduct of research, and mentor–mentee relationship (table 1). Over the year, we have follow-up sessions with the graduate students in which we discuss how their mentor–mentee relationships are working and solicit suggestions for improving the ongoing guidance and programming provided to the undergraduates. Assessment of the graduate mentors included their mapping their mentoring plan for the undergraduates in their interdisciplinary research team before the graduate mentors began research with the undergraduates and, at the end of the yearlong program, the graduate mentors provide short essays reflecting on their workshop training relative to their actual experience as mentors. The quotes that we provide here illustrate the common themes reported by the students.

## Results

The workshops enhanced the students' self-efficacy.

**Graduate students.** Despite 87% of the graduate students stating that their own research was interdisciplinary and 93% stating that their faculty advisor's research was interdisciplinary, 70% indicated they had not taken a course on how to conduct interdisciplinary research prior to the workshop. All of the graduate students had completed an online responsible conduct of research module required by the university, but 57% had not taken a responsible conduct of research course emphasizing ethical decisionmaking. Two-thirds (64%) had not served as a primary supervisor for an undergraduate researcher, and two-thirds (64%) had not received training as a mentor for undergraduates.

At the end of the workshop sessions, the graduate students reported gains in their skill levels, ranging from 11% to 23% for specific interdisciplinary research skills, 17% to 29% for responsible conduct of research skills, and 14% to 24% for mentoring skills (figures 1, 2, and 3).

For the graduate students' overall skills in interdisciplinary research, the average gain was 1.0 intervals (standard error [SE] = 0.1), a gain of 21% (figure 1). The average gain was 1.0 (SE = 0.1) for their skill in building a mentee's confidence for interdisciplinary research project, a gain of 20%.

For their overall skills in responsible conduct of research, the average gain was 1.2 intervals (SE = 0.1), a gain of 24% (figure 2). The average gain was 1.1 (SE = 0.1) for devising how to build a mentee's confidence with responsible conduct of research, a gain of 21%.

For their overall skills in a mentor–mentee relationship, the average gain was 1.2 intervals (SE = 0.2), a gain of 23% (figure 3). The average gain was 1.0 (SE = 0.1) for building a mentee's confidence, a gain of 20%.

At the end of the program year on written surveys, 93% of the graduate students said they were better mentors than before the interdisciplinary research program; 80% said the workshop definitely improved their mentoring; and 92% reported that they had an ongoing interest in mentoring undergraduates for interdisciplinary research.

**Undergraduate students.** Of the undergraduates, 61% had no previous research experience, and 91% had no training about the mentor–mentee relationship. For each of

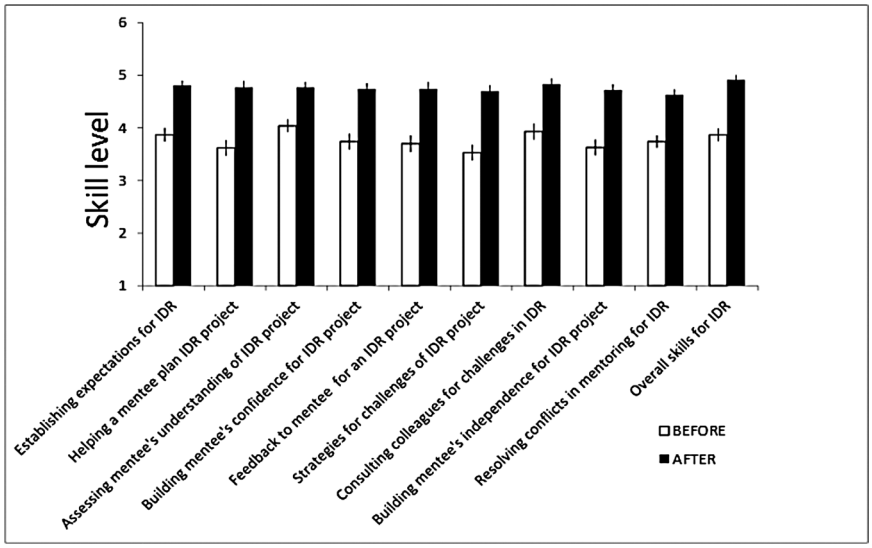


***Figure 1. Graduate mentors' self-assessment of skills before and after the interdisciplinary research session. The skill levels were rated 1 (no skill), 2 (very low skill), 3 (low skill), 4 (moderate skill), 5 (high skill), or 6 (very high skill), and a Mann–Whitney test, at $\alpha = .05$, $p < .01$, was performed for all comparisons. Mean + 1 SE is shown. Abbreviation: IDR, interdisciplinary research.***

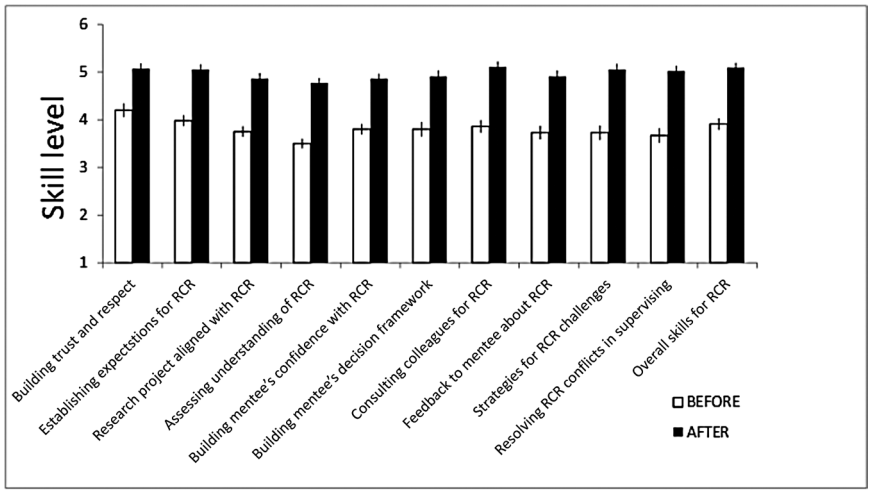


***Figure 2. Graduate mentors' self-assessment of skills before and after the responsible conduct of research session. The skill levels were rated 1 (no skill), 2 (very low skill), 3 (low skill), 4 (moderate skill), 5 (high skill), or 6 (very high skill), and a Mann–Whitney test, at $\alpha = .05$, $p < .01$, was performed for all comparisons. Mean + 1 SE is shown. Abbreviation: RCR, responsible conduct of research.***

the sessions in the workshop, the undergraduate students reported gains in their skill levels, ranging from 29% to 33% for specific interdisciplinary research skills, 24% to 30% for responsible conduct of research skills, and 23% to 32% for mentoring skills (figures 4, 5, and 6).

For the undergraduates' overall skills in interdisciplinary research, the average gain was 1.7 intervals (SE = 0.1), a gain of 33% (figure 4). The average gain was 1.6 (SE = 0.1) for their skill in building confidence for an interdisciplinary research project, a gain of 32%.

For their overall skills in responsible conduct of research, the average gain was 1.3 intervals (SE = 0.1), a gain of 27% (figure 5). The average gain was 1.4 (SE = 0.1) for building their confidence with responsible conduct of research, a gain of 28%.

For their overall skills in a mentor–mentee relationship, the average gain was 1.6 intervals (SE = 0.1), a gain of 31% (figure 6). The average gain was 1.5 (SE = 0.1) for developing confidence in how to do research, a gain of 30%.

At the end of the summer phase of the program (9 weeks of full-time research), when they were asked how well the workshop prepared them for the research work (using a 5-point scale: 1, *not very well;* 5, *very well*), the percentage of undergraduates rating the workshop as 4 or 5 was 65%, 74%, and 65% for interdisciplinary research, responsible conduct of research, and mentor–mentee sessions, respectively, indicating that the majority of students found value in the workshop. Only 12%, 5%, and 15% of the students rated the interdisciplinary research, responsible conduct of research, and mentor–mentee sessions as 1 or 2. Two students' written comments were typical: "I felt that this program gave me the opportunity to figure out if research is for me. I learned from the workshops how to handle things and what I might expect," and "The orientation sessions really shaped my views on interdisciplinary research greatly because they were my first encounter with the concept and what really impacted me the most about those sessions were the conceptualization of interdisciplinary research as a dynamic process; a model that can be applied to almost any situation where several disciplines converge to create a finished product."

For an assessment of the undergraduates' professional and interpersonal development as it relates to work on an interdisciplinary research team that was independent of their own viewpoint, at the end of the summer phase of the program, we asked the graduate student research mentors and the faculty mentors via a written survey to rate the undergraduates in their discipline on a scale of 1–5, with 5 being

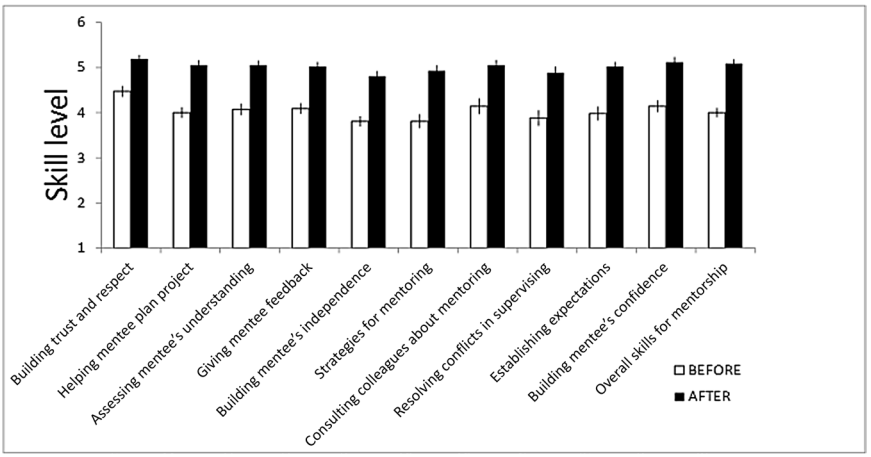


***Figure 3. Graduate mentors' self-assessment of skills before and after the mentor–mentee relationship session. The skill levels were rated 1 (*no skill*), 2 (*very low skill*), 3 (*low skill*), 4 (*moderate skill*), 5 (*high skill*), or 6 (*very high skill*), and a Mann–Whitney test, at* α = .05, p < .01, *was performed for all comparisons. Mean + 1 SE is shown.***

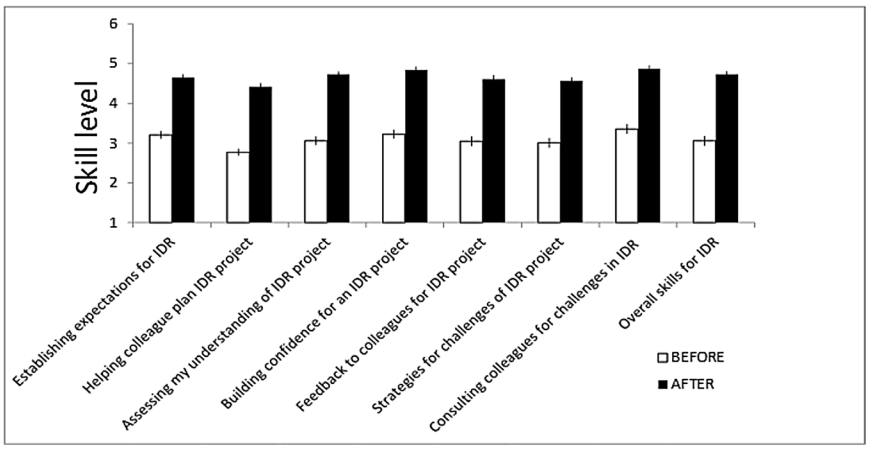


***Figure 4. Undergraduates' self-assessment before and after the interdisciplinary research session. The skill levels were rated 1 (*no skill*), 2 (*very low skill*), 3 (*low skill*), 4 (*moderate skill*), 5 (*high skill*), or 6 (*very high skill*), and a Mann–Whitney test, at* α = .05, p < .01, *was performed for all comparisons. The error bars represent the standard error. Abbreviation: IDR, interdisciplinary research.***

the best score. For the ability to work with the mentor as a research mentor, the graduate students' mean rating of their mentees was 4.6 (SE = 0.1), and the faculty mentors' rating was 4.4 (SE = 0.1). For the undergraduates' ability to work with others in collaborating, the graduate students' mean rating of their mentees was 4.5 (SE = 0.1), and the faculty mentors' rating was 4.4 (SE = 0.1). Relative to the undergraduates' self-confidence with respect to research, the graduate students' mean rating of their mentees was 4.2 (SE = 0.1), and the faculty mentors' average rating was 3.9 (SE = 0.1).

**Reflections by the graduate students.** When asked at the end of the 12-month program, the graduate student research mentors unanimously said the workshop training combined with this interdisciplinary research experience was valuable to them. Their reflections in their essays included narration of situations we had prepared them for during the workshop. In particular a common theme in their essays was the need for frequent, open and clear communication to develop and maintain a well-functioning team. One student began with mixed feelings about interdisciplinary research because of a prior experience: "Ordinarily, meetings on a very small concept would take up to two hours just because what a term means to one is different if not opposite." Then the student summed up the experience with our program: "I learned the art of reaching out and communicating ideas to people who may not be in my field and listening to people of diverse opinion as well as learning new things." Another student stated, "I have learned that interdisciplinary research requires an open mind and flexibility when dealing with a diverse group of researchers. There are different customs and practices across disciplines that require flexibility on the part of everyone involved with interdisciplinary research." A typical response about the workshop on ethical decisionmaking for responsible conduct of research was from a graduate student who found that "the responsible conduct of research approaches very useful in setting forth in my mind the types of boundaries and ethical situations that impact research and the different individuals involved. I use it as a guide for my own behavior and have shared aspects of it with other students that I have mentored." A student provided the example of having to discuss with undergraduate mentees the ethical ramifications of working with data and having "to explain to students that working with data does not constitute ownership of data, and that writing up of research findings must follow a clear 'chain of command' permission process before data are used in any publication, paper, or poster."

The mentorship training plus subsequent follow-up discussions with the graduate students helped them to reflect on what they learned and their application of that. A typical comment: The program "has enabled me to learn the best practices of mentoring. At the onset [the workshop] was a rigorous theoretical exposure to the principles and practice of the task ahead, followed by an actual internship-like real

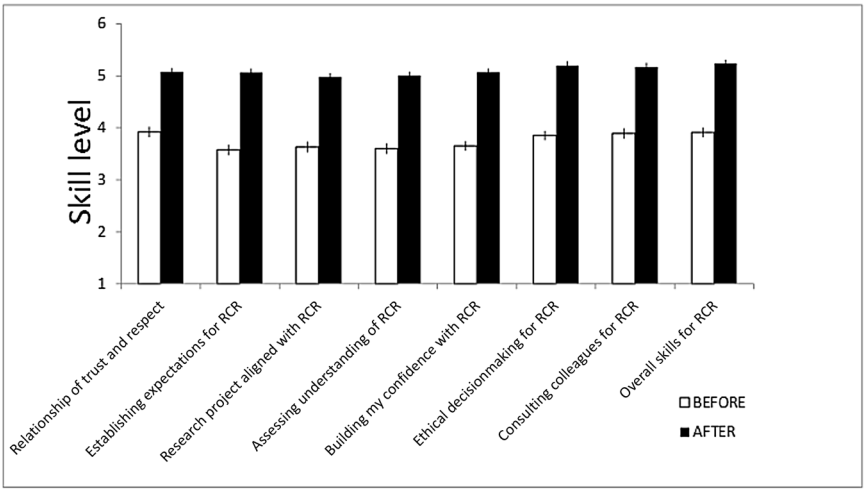


***Figure 5. Undergraduates' self-assessment before and after the responsible conduct of research session. The skill levels were rated 1 (*no skill*), 2 (*very low skill*), 3 (*low skill*), 4 (*moderate skill*), 5 (*high skill*), or 6 (*very high skill*), and a Mann–Whitney test, at $\alpha = .05$, $p < .01$, was performed for all comparisons. Mean + 1 SE is shown. Abbreviation: RCR, responsible conduct of research.***

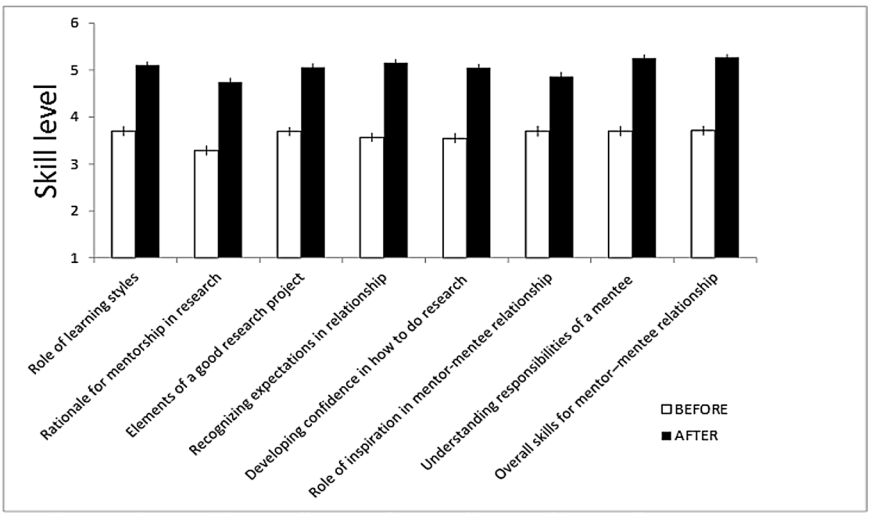


***Figure 6. Undergraduates' self-assessment before and after the Mentor–mentee Relationship session. The skill levels were rated 1 (*no skill*), 2 (*very low skill*), 3 (*low skill*), 4 (*moderate skill*), 5 (*high skill*), or 6 (*very high skill*), and a Mann–Whitney test, at $\alpha = .05$, $p < .01$, was performed for all comparisons. Mean + 1 SE is shown.***

mentoring. The challenge is a situation where you are a mentor in a project of which you are only half aware. Navigating through that with a mentee who looks up to you as a source of direction can be stressful. The main thing I have learned is that the mentor–mentee relationship is a two-way process" with both learning new things, so the mentor's role is to build the mentee's confidence. In reference to learning styles, a graduate student reported: "The most important thing I have learned about mentorship is that two mentees should never be treated exactly the same. We all have unique personalities and needs, and in most cases equal treatment would not be beneficial for any of us. Some students require (and often prefer) a more hands-on relationship and some flourish with one that is hands off. By customizing my mentorship approach to each student, I think that my relationship and mentor effectiveness with each has been greatly improved." Another graduate student commented, "I think that the most critical thing I learned was that mentoring actually required a lot of listening. By actively listening to what my students were saying, I could better discern their needs. Amazingly, if a frustration or problem arose, I found that just by listening and offering a small tidbit of advice the problem often went away or the student figured out how to solve it. This gave the student a sense of confidence in being able to problem solve." Many graduate students wrote about the need to establish expectations from the outset—for example, "I also found that mentoring involved setting clear and consistent expectations. Not overly complicated or detail oriented expectations but clear and guideline based expectations. One trap I did not want to fall into was micromanaging. By setting a basic set of principles from the beginning on managing time and goals, the project flowed smoothly." And most of the graduate students wrote of the rewards for themselves—for instance, "It was great seeing her progress as a scientist and make the effort to continue her scientific endeavors in the future. Hearing she was accepted into a graduate program and offered an assistantship has been my favorite mentoring moment so far and I look forward to mentoring again."

**Outcomes for the undergraduate students.** When asked at the end of the year in an online survey, the vast majority (95%) of the undergraduates said they really liked the interdisciplinary research experience and felt they received sufficient preparation. At the outset, while the students were intrigued by the idea of interdisciplinary research, they had little idea of what interdisciplinary research was and would require of them. As three students explained, (1) "I was not aware of how much different majors can be interrelated," (2) "I never realized the amount of knowledge you can gain by putting yourself into the field with no prior knowledge," and (3) "I did not care for interdisciplinary research previously, thinking my discipline to be the only thing I needed

to know. The workshop really showed the broadness of the problems that could be solved through collaboration." Also, many undergraduates commented on how the workshop reduced their anxiety about not knowing "everything" and helped them navigate their new professional relationships. They said it gave them a framework of what to expect and what would be expected of them. A student summed it up this way: "Working with individuals from other disciplines was difficult on a cultural level as opposed to what I expected to be difficult—academic level. There were differences in what deadlines and expectations meant depending on the discipline of origin." Another observation made by a number of the students was how jargon of the discipline impeded understanding in their interdisciplinary research team meetings. An example was that for geologists, detritus refers to ground-up rock—that is, inorganic material, whereas for biologists, detritus means decayed organic matter in the soil. Because the students were made aware of such differences in terminology across disciplines, they had the courage to intervene when they recognized this "talking past each other" by team members. The students realized that the workshop prepared them for such situations and learned in actual practice the value of and, therefore, the need to establish common ground within the interdisciplinary research team. By far, the most frequent comments by the undergraduates were about their graduate student mentors. A typical statement was the following: "The mentors were extremely helpful and provided a lot of constructive criticisms" and so made it possible to thrive in the interdisciplinary research environment.

## Discussion

Immediately after the workshop, the perceived gains by the undergraduates were substantial, as we expected because most of this group had no or limited research experience. With their workshop, we achieved what we set out to do—alert them as to what challenges to expect in interdisciplinary research, in particular the interpersonal issues that can derail interdisciplinary research.

Initially, we had set out to base the training of the undergraduates in the same way as the graduate students, with emphasis on recognition of interdisciplinary research hurdles as presented in the research literature written about interdisciplinary research. We learned very quickly that in contrast to advanced graduate students and people with doctoral degrees, whose training and experience typically is shaped by the norms of a discipline, undergraduates have not yet assimilated the domain of the discipline in which they are majoring. Thus, we changed our strategy so much of our discussion with the undergraduates focused on developing professional interpersonal and communication skills, with examples from interdisciplinary research situations that illustrated what they might encounter (e.g., discussion of the video clip in which Watson (biologist) and Crick (physicist) talked about the need to respect different points of view, and learn enough of the other discipline to understand the complexity of the research question).

All of the graduate students had done graduate-level research, some for three or four years, and a third of them had some experience with mentoring undergraduate research. Therefore, it was not surprising that the immediate workshop gains for the graduate students were smaller than those for the undergraduates. However, the essays that the graduate students wrote at the end of the year indicated that they had internalized the workshop concepts and applied them. Therefore, both groups benefited, at the very least in terms of enhanced self-efficacy, but in different ways, reflecting their different academic stages.

Initially, faculty were concerned that graduate students would not have time for the workshops. However, by the third year of the program, faculty saw the value of the workshops, and they wanted their graduate students to participate in the program. The undergraduates and graduate mentors thrived in the program and produced publishable research. Furthermore, a third of the graduate students signed up for at least one more year.

In summary, combining the three sessions—how to do interdisciplinary research, ethical decisionmaking for responsible conduct of research, and the mentor–mentee relationship—into a workshop helped students see how these topics relate and in particular the value of that understanding for successful collaborative interdisciplinary research. The group activities of the sessions reinforced both the creative and interpersonal skills needed for interdisciplinary research, ethical decisionmaking for responsible conduct of research, and the mentor–mentee relationship. Moreover, designing the workshops in parallel gave the undergraduates and their graduate student research mentors a common foundation for handling the potential pitfalls of interdisciplinary research, for navigating the fuzzy areas of responsible conduct of research and for overcoming mentor–mentee difficulties, so they could have a productive and enjoyable interdisciplinary research experience together. This approach of offering a workshop combining interdisciplinary research, responsible conduct of research, and mentoring to undergraduates and graduate mentors in parallel can be adapted to other mixes of disciplines, for example social sciences, with an appropriate choice of simulated problem situations. Now we are trying a different version of the workshop, by incorporating the material and format into a research methods course for freshmen, with postdoctoral associates trained for and then delivering the lessons.

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## Supplemental material

The supplemental material is available online at *http://bioscience.oxfordjournals.org/lookup/suppl/doi:10.1093/biosci/biv017/-/DC1*.

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