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Transformative Pre-research Mentorship Design: Jump-Starting Undergraduate Research Experience in Molecular Biology

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Abstract

Performing research greatly enhances undergraduate educational experiences and science-based career trajectories, yet there are many obstacles in implementing research training both for students and faculty. In particular, undergraduates must gain theoretical knowledge and practical skills prior to attempting molecular and cellular biology laboratory research. Individual research training is extremely time consuming for both students and faculty, and by the time students gain enough knowledge and experience through their majors' curriculum, it is often too late for them to pursue more rigorous research opportunities and put their skills to use. In this article, I describe a streamlined design of a semester-long research mentorship that focuses on training first year undergraduate students in a small group setting. As an experienced molecular research mentor, I narrowed down essential skill sets and theoretical knowledge to jump-start their research that transformed their undergraduate research experiences. The pre-research mentorship gears toward transforming students' pre-conception of what authentic research experience entails, enlightening them with existing opportunities for original research early in their academic career. The close and focused mentoring from weekly mentorship meetings helps students to align their academic interests and future career paths with specific research areas. The success of the mentorship was reflected by the fact that a majority of the students who completed the mentorship were able to engage in rigorous laboratory research opportunities and either pursued or planned to pursue graduate and professional education in science and medicine. Although the model of mentorship was developed for molecular research, the key features of the mentorship can be applied to other disciplines to enhance the undergraduate research experience.

Keywords: pre-research mentorship, molecular biology, transformative

Background: Undergraduate Research and Biology Education

Since the publication of BIO 2010 (2003): Transforming undergraduate education for future research biologists by the National Research Council, there has been numerous discussions as to how educators might transform the undergraduate biology education experience (O'Connor et al., 2011; National Academies of Science, Engineering, and Medicine, 2015). In particular, undergraduate research (UR) is considered a "best practice" in transforming students' overall educational experience by providing students with real problem-solving skills and prepares them better for their future scientific and professional careers in STEM fields (Lopatto, 2007; Thiry, Laursen, & Hunter, 2011). The value of UR is strongly reinforced by the large number of published studies discussing the positive impact of UR in enhancing education experiences as well as graduate and professional education trajectories (Eagan et al., 2013; Elrod, Husic, & Kinzie, 2010; Hathaway, Nagda, & Gregeman, 2002; Hunter, Laursen, & Seymour, 2006; Kremer & Bringle, 1990; Lopatto, 2003; Lopatto, 2004; Seymour, Hunter, Laursen, & DeAntonni, 2004).

While transformation of undergraduate education with UR in the U.S. is vitally important, and incorporation of research into curriculum is well documented, designing and implementing an effective UR program presents obstacles for both faculty and students at primarily undergraduate teaching institutions (Carson, 2007). First, teaching intensive institutions where most UR is carried out, the burden of student research training usually falls on faculty, who have heavy teaching loads and cannot rely on support from graduate students, postdoctoral researchers, or in-lab research scientists. Secondly, resources to fund student projects and procure instruments are often limited. For undergraduates, a major challenge is that they must gain an abundance of theoretical knowledge and practical experience that are quite new and complex to them prior to successfully conducting laboratory-based research in biology—even more so in molecular biology. Based upon conversations with new research students and my own UR experience many years ago, first and second-year students are quite intimidated by the basic instruments and technical terminology commonly used in the laboratory.

The Development of Pre-Research Mentorship

Over several years of working with undergraduates in my own laboratory and trying different methods to prepare them for research, I felt an urgent need to develop a special training strategy to move students from their “Taken for granted frames of reference,” particularly as they pertain to “the paradigms of science and mathematics” (Mezirow 2003). I identified the timing of basic training as a pivotal factor for undergraduates to gain meaningful research experience. On prior occasions, thinking it would save training time, I would wait to recruit suitable research students who had gained sufficient foundational knowledge and basic laboratory training through their major’s program of study as juniors. However, the actual result was that by the time the focused training was complete, it was too late for students to use their skills effectively to perform original research as seniors. On the assumption that the recruiting has to occur much earlier, I selected a small group of freshmen students to invite them to participate in a “pre-research mentorship” I created. The selection of students for invitation was primarily based on their laboratory skills, talents I observed, and the level of enthusiasm towards research training and opportunities, not necessarily based on final course grades. Given the extensive scope of molecular research, I carefully narrowed down a set of basic molecular laboratory skills and essential laboratory techniques. The goal of the pre-research mentorship was to 1. provide students with a basic understanding of research process, 2. to reduce the intimidation of the laboratory setting (e.g. equipment and reagents), and, most importantly, 3. to expose undergraduate students to a variety of available research opportunities early in their academic career. A small group setting allowed me to train more than one student at a time; also, the small groups allowed for individual attention to each student’s learning style. The trial mentorship was taught outside my regular teaching load, and enrolled students received one credit hour for participating.

The Core Pre-Research Mentorship Design for UR training

In the mentorship class, students began by learning how to properly calculate and prepare common chemical reagents since much of the lab time is typically spent in the preparation of the reagents. Although all biology majors are required to take one year of general chemistry, they rarely get hands-on experience in preparing the actual chemical reagents for their labs as everything is prepared and set up by a laboratory coordinator who oversees the student laboratory courses. They also learn necessary formulae and equations for reagent preparation. Yet, they rarely have a chance to apply the formulae and appreciate the true value of what they learned in chemistry. For molecular biology techniques, we followed the basic principles and protocols underpinning fundamental molecular lab techniques utilized by almost all molecular laboratories such as nucleic acid and protein handling (Baker, 2005). As the selected students for mentorship completed the first semester of introductory biology lecture and laboratory, the connection to knowledge gained from the introductory courses was brought out and expanded further to connect to the techniques that are used in a customary real laboratory setting, such as DNA purification, DNA gel electrophoresis, and protein quantification techniques. A detailed list of weekly activity and topics is listed in Table 1.

Table 1

Weekly topics and activity/contents covered in mentorship

Week	Topics	Activities and contents
1	Mentorship Introduction	• Group discussion—expectation of being in a molecular research laboratory and conducting research
2	Laboratory notebook keeping	• Group discussion —the essential elements for a proper laboratory notebook • Examination of sample notebooks and comparisons
3-4	Basic molecular reagent preparation, storage, and disposal*	• Introduction of chemicals (e.g. buffering agents, acids, bases) • Basic formulae for preparing reagents and calculation practice • Introduction to basic instruments used in molecular biology
5	Techniques on cultivating and handling cells	• Introduction of cell lines • Discussions on attributes of different cell types-caveats of cell culture

Week	Topics	Activities and contents
		• Basic techniques in handling cells; Growth curve
6-9	Principles of basic molecular techniques*	• Micropipetting practice • Principles of - Isolation of nucleic acids; nucleic acid concentration measurement - Gel electrophoresis - Polymerase Chain Reaction - Restriction digest and cloning - Epitope tagging; Cell lysis - Biochemical protein purification - Protein sample preparation - SDS-PAGE - Basic light and fluorescence Microscopy • Data based problem-solving assignments and review
10	Introduction to scientific literature	• Elements of scientific literature and basic approaches to article reading • How to conduct science literature research
11	Elements of scientific presentation	• Best practices • Sample oral presentations • Formatting of effective oral presentations
12-14	Presentation practice	• 10 minute student presentations
15	Discussion on research misconduct and ethics	• Reading and discussion of articles that bring up data fraud/statistical pitfall • Discussion of unethical conduct cases
16	How to seek research opportunities	• Discussion on finding and assessing research opportunities on campus and beyond (e.g. NSF sponsored Research Experience for Undergraduate program introduction; other opportunities)

Note. The topics with * indicate that basic information and principles of protocols discussed were adopted from “At the Bench: A Laboratory Navigator,” updated ed. by K. Baker (2005).

We also spent some time discussing the elements of good laboratory records via critiquing good vs. bad laboratory notebooks. To track progress at the end of the semester, students were expected to apply learned techniques by completing a set of problems that included selected data from research publications which they did perform quite well.

Thus far, two cohorts of students have completed the pre-research mentorship; the first cohort consisting of five students, and the second with ten students. The transformative impact of training is clearly evident from the students' likelihood of pursuing research opportunities. For example, mentored students in the first cohort (n=5; 40% under-represented minorities (URM)) had 100% pursue research experiences in faculty laboratories over a minimum of two semesters. The second cohort (n=10; 20% URM) resulted in 80% of students, who are currently juniors as of fall 2018, being engaged in active research on campus for over two semesters and continuing to do so. Two sophomore students from the combined cohorts were selected for the NSF sponsored summer Research Experience for Undergraduate (REU) programs. All students who engaged in active research on campus had opportunities to present their original research during the Georgia College Campus Research Symposium as well as at regional and national research conferences. 100% of the first cohort students either began graduate programs in biomedical fields or are in the process of applying for medically oriented professional schools.

Linking Transformative Learning with Pre-Research Mentorship

According to Mezirow (2003), transformative learning is defined as "learning that transforms sets of fixed assumptions and expectations." In addition, Mezirow notes that reflective judgment about students' own perspective is an essential condition for transformative learning. The exit survey at the end of the mentorship and follow-up interviews provided an excellent opportunity to observe critical reflection of student assumptions which, in turn, reflected student engagement in the transformative learning process. For example, one student expressed her initial surprise of "how tedious" technical procedures really were on her exit survey, but, on the follow-up interview, she said that understanding scientific principles behind procedures really helped her adjust to learning the procedure properly and performing experiments in her research project successfully. Overall, all mentorship students engaged in research after completing the mentorship reported the exposure to basic laboratory settings and to molecular research greatly enhanced their learning the requisite technical skills and developed more realistic expectations in pursuing original research as compared to their original assumptions.

Although transformative learning appears to lead to a more mature, autonomous, "developed" level of thinking, Merriam (2004), in her forum article, argues that a certain level of cognitive development would be a prerequisite for engaging in the meaningful transformative learning process. Drawing from her critical reflection of transforming theory, I believe that the pre-research mentorship significantly contributes to cognitive development of undergraduate researchers and serves as critical prerequisite to meaningful undergraduate research experience. In particular, it is extremely important to correct students' prior misconceptions about research. Namely, the misconception that experiments often do not produce incontrovertible results, and instead show that they are much more time-consuming processes requiring frequent trouble shooting and trying out many new strategies to probe answers that are experimentally possible. Indeed, there is very little in their early biology experiences in high school or freshmen level classes that prepares them for real bench work as students typically follow proscriptive lab manual procedures with all reagents prepared and laid out for them, thus obtaining expected results almost every time they conduct experiments.

Another noteworthy transformative effect of the pre-research mentorship is the close and direct mentoring it engenders. A recent review by Linn, Palmer, Baranger, Gerad, and Stone (2015) identifies such mentoring as an essential component for successful support of undergraduates considering careers in science. The review further points out that "successful mentoring balances the dual goals of helping undergraduates deepen their understanding of science and guiding them to develop a scientific identity via articulating their knowledge, reasoning, or problem-solving skills." The mentorship design supports all aspects of building individual scientific identity by exposing students to reading a variety of research literature and seeking out research opportunities that would fit their research interest best along with frequent opportunities to share their scientific interests. Finally, pre-research mentoring provides opportunities for students to communicate and ask insightful questions. In the small group setting of the mentorship, everyone is geared to actively participate in weekly meetings discussing their distinct interests, personal backgrounds, strengths, and weaknesses. Following up on their interests in research opportunities greatly enhanced the high success rate of the post-mentorship research engagement described above. Representative of sentiments echoed by many students in the class was their being significantly less intimidated by the laboratory setting after learning the terminology of common chemical reagents and instruments. Likewise, the students valued the connection to what they learned to other laboratory-based classes such as organic chemistry.

Conclusion

In summary, the implementation of a pre-research mentorship is effective in transforming undergraduate research. From the students' perspective, it promotes students' confidence in viewing themselves as potential researchers because it 1. demystified the laboratory and 2. bridged the gap between the prior perception they held of the requirements for research and the actual knowledge and technical skills required to produce meaningful research data. In particular, the early timing in their undergraduate career encourages students to actively pursue and engage in research opportunities early. This early research boost in turn allows for much needed time to generate meaningful, experimental data presentable at professional venues. Indeed, the benefit students gain from research is known to be significantly enhanced in multi-year research experiences (Thiry, Weston, Laursen, & Hunter, 2012). Finally, the research experience confers a host of personal, intellectual, and professional benefits to students along with an increased capability of improving their future careers and professional identity development. From the faculty side, the pre-research training reduces the time burden to the potential UR mentors. Students who completed the mentorship can now operate some of the basic instruments, calculate and prepare basic chemical reagents, and keep good laboratory records as they carry out specific experiments, all of which would otherwise take months to learn. The UR mentors can, therefore, focus on aligning research students to their specific research interests and on helping develop their bench work skills tailored to specific experiments. While the model I developed for a pre-research mentorship was based on my own interest in molecular biology laboratory research, the key features of the mentorship—early selection of mentees and a highly streamlined list of essential training elements needed for a specific type of research—can be expanded and applied to other areas of interest in undergraduate research.

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