The Biophysicist

Project Symphony: A Biophysics Research Experience at a Primarily Undergraduate Institution

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Interdisciplinary research experience in biophysics

Increased attention has been conferred upon interdisciplinary science, technology, engineering, and math (STEM) education to prepare students for deeper understanding to address complex challenges (1–3). Particularly at the undergraduate level, there is recognized value in providing opportunities for students to integrate knowledge across disciplinary boundaries (4–7). In addition to core technical knowledge, it is beneficial to confer behavioral skills that allow students to perform well with others through effective communication, time management, and teamwork (8). Undergraduate research experiences have been considered to be a powerful learning tool, engaging students and stimulating their enthusiasm, thereby improving academic performance and persistence in science and preparing students for advanced degrees and careers in STEM fields (9–17). This report, the culmination of more than a decade's work with undergraduate students, presents practices demonstrating that early exposure to the interdisciplinary field of biophysics can be effectively introduced at a primarily undergraduate institution (PUI) level through a well-structured research plan involving undergraduates with different STEM majors. The management of this group, called "Project Symphony" (18), overcame the challenges of sustaining research activities at a PUI via the incorporation of 2 essential elements of success: (a) establishment of a cooperative learning variant whereby students work together to maximize individual learning and each other's learning; and (b) promotion of an integrated understanding via interdisciplinary biophysics projects.

Undergraduate journey in Project Symphony with cooperative learning and team building

Project Symphony is a research group at a PUI, with solely undergraduate students. The name Project Symphony results from a vision in which all group members work together in harmony to achieve shared goals, while maintaining individual interests and supporting each other, analogous to the orchestration of a musical symphony. This idea is similar to the concept of cooperative learning found in many classroom environments, which involves students working together to accomplish shared goals and enhance the current

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understanding of a topic (19, 20). Project Symphony embodies a different form of cooperative learning that facilitates impactful research at a PUI, where students may be involved for up to 4 years of research in the field of biophysics. The uniqueness of Project Symphony includes early commencement of research training (from freshman year) and recruiting students from diverse disciplines (from biology and chemistry to physics, mathematics, and computer science). When recruiting students for the Project Symphony group, the most important consideration is a student's enthusiasm toward research, the willingness to join the cooperative culture of a research lab, and the availability to participate in summer research, at least part time. No specific grade-point average requirements are set when accepting students into the group. Each year, the undergraduate researcher progresses through stages that mark milestones in his or her development as a scientist. The 4 stages of responsibilities and roles undergraduates play in a typical 4-year research experience are described in the following.

Stage 1: apprenticeship period (freshman year before summer)

Undergraduates joining Project Symphony are encouraged to work an apprenticeship period starting from the winter intersession of the first year, i.e., during the break of 2 to 3 weeks in January before the spring semester begins. During this winter break, new students may acquire their first taste of the full experience of being involved in research. All available group members join the research activities for the majority of each day, with specific focus on training and welcoming newly joined students to the culture of the research group. After research training during the winter intersession, the period can extend into the spring semester, through the pairing of apprenticing students (mentees) with experienced students (mentors) on the basis of interests in the specific projects, subject to mutual availability (class schedules). This time is well spent in making new students feel comfortable in research and enhances the chances of retaining them in the group.

Stage 2: project development

The crux of success of Project Symphony is in the summer experience. Many research group members experience summer research in which they spend time together in the lab for the major part of the day (from a few weeks to 10 weeks). This simulates the environment of the life of a scientist and serves as a wonderful bonding experience among group members for both new and seasoned ones. Near the end of the summer, students develop an increased level of comfort with the technical skills in the laboratory and have good grasp of a given project. At summer's end, all group members attend the American Chemical Society Fall National Conference, a capstone event to celebrate research activities. All group members view the conference experience as a reward for the intense summer-long research activity and as something to be excited about and anticipate. Some detailed tips for taking undergraduates to professional conferences have already been shared through a published blog post (21). Many students at the authors' institution are local and elect to commute during the summer. This can provide flexibility for students who have multiple commitments at home, allowing them to support family members or explore additional opportunities. The research stipend and conference attendance are mainly supported by National Science Foundation (NSF) Research in Undergraduate Institutions grants through the PUI, while summer housing, where necessary, is provided by the home institution. It is often during the summer months that transitions between the stages take place: mentees become mentors, and lab members grow more accustomed to the idea of exerting sustained effort to achieve goals.

Stage 3: experienced member transition

By the time a student has been involved with research for about 2 years, the student often begins to take on leadership roles in the lab. A nascent leader will facilitate the experiments

Table 1. Examples of subprojects and interdisciplinary project teams.

Specific individual project theme	Project team[a] (student's major)
Experimental	
Determination of water permeability using model membranes: microscopy and fluorescence spectroscopy	Biology, chemistry, biochemistry
Investigation of thermal properties of model membranes: differential scanning calorimetry	Chemistry, biochemistry
Determination of electric property of model membrane: electrophysiology	Physics, biochemistry
Structural determination of model membranes: vibrational spectroscopy (confocal Raman spectroscopy)	Chemistry, biochemistry
Kinetic studies of self-assembly of lipid molecules at the interface: tensiometry	Chemistry, biochemistry, biology
Computational modeling (internal collaboration)	
Molecular dynamic simulations and calculation of the potential of mean force for transport through bilayers	Mathematics, computer science, biochemistry
Mathematic	
Developing mathematic model for small molecule permeation across the semipermeable lipid bilayer that will be applied to the interpretation of experimental data	Computer science, chemistry, physics, mathematics
Software development	
Microscopic image analysis and subsequent coding and software development for accurate extraction of permeability value from the experimental data	Computer science, chemistry
Device fabrication and engineering (external collaboration)[b]	
Design and fabrication of high-throughput device for the construction of model membranes that will be used for the permeability determination and electrophysiology studies	Physics, biochemistry

[a] Among 54 research participants who have graduated, 15 students were majors from physics, computer science, mathematics, and 39 students were majors from biology, biochemistry, and chemistry.
[b] About 1 to 2 students perform research at the University of Tokyo in Japan during the summer (NSF-funded collaboration).

undertaken by newer members of the subgroup and will begin to prepare amassed data, in consultation with the principal investigator, for presentations (both oral and poster), and eventually for peer-reviewed publication. Students at this stage are also involved in maintaining good laboratory practices to run the lab effectively and safely, including maintenance of shared instruments, coordinating common tasks and responsibilities with specific members, and keeping a logbook for chemicals and the use of instruments.

Stage 4: professional development

Students in this stage play critical roles by providing much of the continuous energy and passion needed for projects to keep moving forward. They also provide guidance and emotional support to newer students, who often struggle with feelings of being overwhelmed. The most experienced students lead conversations among group members regarding important logistics (e.g., when instruments are available or what can be reasonably accomplished in the limited time that a student has outside of regular class studies) and share experiences regarding how they managed time between course works and research. This is the period in which a senior member of the group can exercise a managerial role in leading peers and learning to resolve any conflicts.

Designing research experience for integrated understanding

The current overarching goal of the Project Symphony group is aimed at the improved understanding of the cell membrane through building artificial membrane mimics. The inherently interdisciplinary nature of this biophysics research goal is ideally suited for cooperative learning, as it offers students from different disciplines the opportunity to actively work together, to enhance understanding, and to provide a broad view of scientific research. Table 1 shows how the projects and the individual components span experimental, computational, theoretic, and engineering approaches, working collaboratively at the intersection of biology, physics, chemistry, mathematics, and computer science for integrated understanding. Each of the individual projects are carried out by a team (termed "subgroup") of 2 or 3 collaborating students. Although the students performing individual projects use differing techniques, they all contribute to a meaningful outcome via actively participating in the learning process. For example, one team investigates the effect of a drug on thermal properties of particular model cell membranes. This team will collaborate with another team whose goal is to study the structural modification of the same system by using Raman spectroscopic techniques. Therefore, collaborations and regular exchange of findings are achieved by both working together within a team and through discussion outside of the team. Students bond with subgroup partners by jointly sharing labor in support of the unique research objective of that subgroup, while maintaining an awareness that the research goals are part of a larger objective. Through constant communication, students have many opportunities to perfect science communication skills, as well as offer new perspectives to others. This also allows students to feel more comfortable when presenting work to the broader scientific community and the general public. The individual subgroup projects are harmonious and in support of a larger group goal so that students can be exposed to a variety of methods for understanding a bigger picture. Experiencing such a model of effective teamwork across a multidisciplinary matrix of fields enriches the student's ability to adapt and thrive in a college environment and when he or she enters the workforce.

Reflections and recommendations

A total of 54 students (65% female and 35% male) who have been members of Project Symphony have graduated thus far. Of these, 43 have either finished or are progressing to advanced degrees (PhD, MD, or MS), and 11 are currently employed full time with a BS terminal degree. Sixteen students who advanced to PhD programs are now studying in highly interdisciplinary research fields, such as biophysics or biochemistry, at leading institutions. They have coauthored peer-reviewed papers, serving as a further indicator of the collaboration that occurs in the laboratory, with 14 peer-reviewed papers published since 2009 with 39 undergraduate coauthors (22). Many of the students present findings at professional conferences at the regional and national level (23) and receive significant early experience in the presentation and acquisition of advanced scientific information.

On the basis of the authors' experiences, the following primary components have been the most effective in starting and sustaining the active undergraduate research group:

(a) recruit students early and offer extended periods of research experiences (i.e., summer research has been the most useful for the authors in providing intense research experiences)
(b) design a research project to promote integrated understanding instead of an isolated project on the basis of individual effort with little opportunity for cross communication
(c) provide positive research group dynamics through research experience combined with frequent socialization and emotional support
(d) promote the cooperative learning of students by building cross-disciplinary research teams with students from diverse disciplines
(e) establish a culture in which all group members feel a sense of belonging and respect (create a research group name and logo and use this for safety gown, mouse pad, etc.)

Project Symphony assembles a collection of minds from different disciplines who are able to approach a problem from multiple perspectives in a supportive environment. By virtue of this, students can learn from peers, become more interested in the subject matter, propose solutions to real-world concerns, and become prepared for a competitive global STEM workforce, all while functioning as a single, cohesive group. The task of building and maintaining a successful undergraduate research program is a challenging one, especially at a PUI. However, it is our belief that the previously described methodology of an undergraduate biophysics research group can serve as a template for others to emulate.

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REFERENCES

1. The White House Office of Science and Technology Policy. Summary of the 2018 White House State–Federal STEM Education Summit. 2018. Accessed 12 July 2020. https://www.whitehouse.gov/wp-content/uploads/2018/06/Summary-of-the-2018-White-House-State-Federal-STEM-Education-Summit.pdf.
2. US Department of Education, Office of Innovation and Improvement. 2016. STEM 2026: a vision for innovation in STEM education. Accessed 12 July 2020. https://www.air.org/system/files/downloads/report/STEM-2026-Vision-for-Innovation-September-2016.pdf.
3. Centre for the New Economy and Society. World Economic Forum. 2018. The future of jobs report. 2018. Accessed 12 July 2020. http://www3.weforum.org/docs/WEF_Future_of_Jobs_2018.pdf.
4. Spelt, E. J., H. J. Biemans, H. Tobi, P. A. Luning, and M. Mulder. 2009. Teaching and learning in interdisciplinary higher education: a systematic review. *Educ Psychol Rev* 21(4):365.
5. Murray, J. L., E. J. Atkinson, B. D. Gilbert, and A. E. Kruchten. 2014. A novel interdisciplinary science experience for undergraduates across introductory biology, chemistry, and physics courses. *J Coll Sci Teach* 43(6):46–51.
6. American Association for the Advancement of Science. 2010. Vision and change: a call to action. Accessed 12 July 2020. https://visionandchange.org/about-vc-a-call-to-action-2011/.
7. American Association for the Advancement of Science. 2019. Levers for change: an assessment of progress on changing STEM instruction. Accessed 12 July 2020. https://www.aaas.org/sites/default/files/2019-07/levers-for-change-WEB100_2019.pdf.
8. IBM Institute for Business Value. 2019. The enterprise guide to closing the skills gap. Accessed 17 May 2020. https://www.ibm.com/downloads/cas/EPYMNBJA.
9. Graham, K. J., E. J. McIntee, A. F. Raigoza, M. A. Fazal, and H. V. Jakubowski. 2016. Activities in an S-STEM program to catalyze early entry into research. *J Chem Educ* 94(2):177–182.
10. Haeger, H., and C. Fresquez. 2016. Mentoring for inclusion: the impact of mentoring on undergraduate researchers in the sciences. *CBE Life Sci Educ* 15(3):ar36.
11. Estrada, M., M. Burnett, A. G. Campbell, P. B. Campbell, W. F. Denetclaw, C. G. Gutiérrez, S. Hurtado, G. H. John, J. Matsui, and R. McGee. 2016. Improving underrepresented minority student persistence in STEM. *CBE Life Sci Educ* 15(3):es5.
12. Lopatto, D. 2004. Survey of undergraduate research experiences (SURE): first findings. *Cell Biol Educ* 3(4):270–277.
13. Olson, S., and D. G. Riordan. 2012. Engage to excel: producing one million additional college graduates with degrees in science, technology, engineering, and mathematics. Report to the President, Executive Office of the President, Washington, DC. Accessed 12 July 2020. https://files.eric.ed.gov/fulltext/ED541511.pdf.
14. Cooper, K. M., L. E. Gin, B. Akeeh, C. E. Clark, J. S. Hunter, T. B. Roderick, D. B. Elliott, L. A. Gutierrez, R. M. Mello, L. D. Pfeiffer, and R. A. Scott. 2019. Factors that predict life sciences student persistence in undergraduate research experiences. *PLOS ONE* 14(8):e0220186.
15. Russell, S. H., M. P. Hancock, and J. McCullough. 2007. Benefits of undergraduate research experiences. *Science* 316(5824):548–549.
16. Seymour, E., A. B. Hunter, S. L. Laursen, and T. DeAntoni. 2004. Establishing the benefits of research experiences for undergraduates in the sciences: first findings from a three-year study. *Sci Educ* 88(4):493–534.
17. Hunter, A. B., S. L. Laursen, and E. Seymour. 2007. Becoming a scientist: the role of undergraduate research in students' cognitive, personal, and professional development. *Sci Educ* 91(1):36–74.
18. Project Symphony. 2020. Project Symphony homepage. Accessed 12 July 2020. https://www.dropletbilayer.com.
19. Smith, M. E., C. Hinckley, and G. Volk. 1991. Cooperative learning in the undergraduate laboratory. *J Chem Educ* 68(5):413.
20. Bangera, G., and S. E. Brownell. 2014. Course-based undergraduate research experiences can make scientific research more inclusive. *CBE Life Sci Educ* 13(4):602–606.
21. Lee, S. 2016. How to make the most of the ACS national meeting when taking undergrads: be organized (but not too much). Accessed 12 July 2020. https://curchem.wordpress.com/2016/02/29/how-to-make-the-most-of-the-acs-national-meeting-when-taking-undergrads-be-organized-but-not-too-much/.
22. Project Symphony. 2020. Publications. Accessed 12 July 2020. http://dropletbilayer.com/publications/.
23. Project Symphony. 2020. Presentations. Accessed 12 July 2020. http://dropletbilayer.com/presentations/.