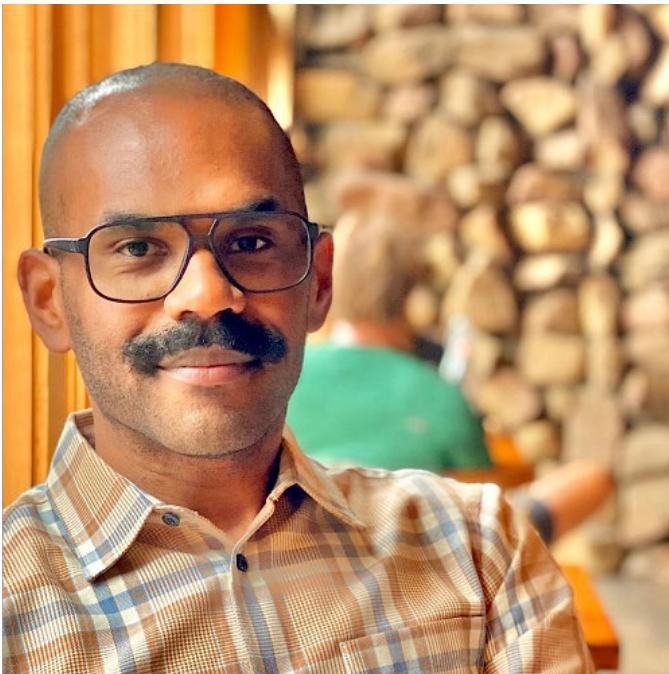


Conducting research at primarily undergraduate institutions

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Undergraduate research and education are critical parts of the scientific ecosystem. Professors at primarily undergraduate institutions (PUIs) bear responsibility for molding young scientists while carrying out high quality research. In this Voices piece, researchers offer inspiring replies to the following prompt: **In your role as a professor, what are the challenges and opportunities when conducting research at a primarily undergraduate institution?**



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Undergraduate research at PUIs is a critical element to the development of the next generation of scientists and needs more recognition

One of the greatest joys of being a professor at a primarily undergraduate institution (PUI) is being there at the beginning of a student's scientific career. Engaging undergraduate students in my research program affords an opportunity for our lab to collectively create a scientific training

ground that: puts theory into practice, is inclusive, and provides a supportive place for a student to try and fail. This is especially critical for students who have historically not been supported and engaged in science. Often, we do this work over the 8-10 weeks in the summer. Our efforts involve intensive training of students not only in technical skills, and safety protocols, but building up their knowledge of the field, communication skills, and confidence to use that knowledge with care and rigor. My aim has been to produce impactful science and daring minds at the ground level. This is hard and constant work. It is work that I and my PUI colleagues enjoy, but also work that must be done while teaching 2-4 classes a semester (sometimes summer), conducting institutional service, as well as family and personal needs. Furthermore, often we are not compensated for this work either through a stipend, course release, or sabbatical accrual.

Undergraduate research is a cornerstone of how science is pushed forward. Whether you are a faculty member at a graduate-focused institution, industry, government, or a PUI, we all have had the same training and we all are invested in doing great science. A remaining challenge is to have better and more recognition by journals, award committees, funding agencies, and our own institutions for the work coming out of undergraduate-based research laboratories. Funding, instrumentation, chemical society awards, and other resources are still prioritized for principal investigators at Ph.D.–granting universities. Our work at PUIs is impactful, highly cited, and worthy of the same visibility and recognition. While some progress has been made, my hope is our institutions and funding agencies continue to invest in the students, faculty, and staff that makes undergraduate research possible.



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Increasing research opportunities for enthusiastic undergraduates

Youth and enthusiasm are the golden opportunities of research with undergraduates. What undergraduates lack in experience and knowledge, they more than make up for with determination and excitement to get the job done.

Chemist, education pioneer, and Mount Holyoke College's founder, Mary Lyon, put an early emphasis on learning in the laboratory and is widely credited with setting the standard for modern science education in a liberal arts setting. Alumna and Chemistry Professors, Emma Carr and Lucy Pickett, each won Garvan medals for their research work with undergraduates. Anna Jane Harrison, the first woman president of the American Chemical Society, also enjoyed teaching and research at Mount Holyoke College. Seeing this rich history of women in science, about one third of our students major in the sciences and actively begin seeking research opportunities as early as their first year. With so many students seeking research positions and a limited number of spaces in our laboratories, we are challenged to find opportunities for all of them.

To this end, we have created classes with built-in research experiences either within a specific laboratory or as a full research class to both provide early research training and give students a taste of research. The collaborative spirit fostered in my "Using data science to find hidden chemical rules" classes led students to write class papers. These papers have either been published or are being pursued further by students who have joined my research team after the class. We hope to continue these research focused courses to broaden research opportunities.



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A pool of potential

Many PUIs share one key thing: they are small, or at least small in comparison to graduate-level research intensive institutions. The fact that PUIs are small is both their biggest benefit and drawback for chemistry faculty working with undergraduate researchers. At small institutions, it is easy for students to have a close relationship with their faculty mentor,

because PUIs typically have a small number of faculty teaching a small number of students. This close relationship leads to more direct faculty-student mentorship in the lab, in part because PUIs rarely have graduate students or post-doctoral researchers to help supervise undergraduate researchers. So, undergraduate researchers from PUIs typically graduate with research skills honed by very focused mentorship and engagement at all stages of their development.

Conversely, the small size of a PUI also presents some serious challenges to conducting undergraduate research. Funding agencies often under-serve PUIs; securing sustainable, long-term funding is extremely difficult with a research team that turns over more frequently than at graduate-level research intensive institutions. The funding agency focus on peer-reviewed articles and impact factors drastically undervalues the key role PUIs play in training future graduate researchers. Similarly, access to cutting-edge research instrumentation and infrastructure is a serious challenge without a nearby (friendly) research-intensive institution.

While most PUIs are individually small, there are many of them which together serve many students. With sufficient support, these teaching-intensive schools collectively provide a large potential pool of highly trained chemists ready for graduate school, industry, or other chemistry-related careers.



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Jumping off the treadmill at high speed

Conducting research at a PUI is both a challenging and rewarding experience. Modern experimental research in physics is very instrument-intensive, especially in the field of non-linear optics, in which my graduate work was focused. At any institution, it can be difficult to obtain seed funding for

isolated pieces of research equipment needed to start an independent lab, especially without preliminary results. This is particularly true if one transitions from an R01 institution to a PUI expecting to continue the research interests pursued during graduate or postdoctoral positions. In my experience, this challenge presented an opportunity for personal and scientific transformation; rather than continuing in my niche of optics applied to biophysical questions, I chose to undertake completely new projects that leveraged the strength of interdisciplinary collaboration at Mansfield University.

Through the Pennsylvania State System of Higher Education (PASSHE) system, I was able to secure funds to initiate novel projects well outside of my comfort zone in collaboration with my colleagues in the biology department. The project with the largest amount of undergraduate participation involves the investigation of the health effects of oral consumption of microplastics in a mouse model. This project has branched out to include investigations of plant uptake of plastics, as well as surveys of plastics in the local water and sediments. All of the students involved in the project thus far have matriculated directly into graduate and professional programs, or the work force. Another project involves decoding cryptobiosis in tardigrades. This has been used as a teaching model by my collaborator in the biology department, Dr. Kristen Long, in her lab-based molecular biology course. Both of these projects contain smaller parts that are amenable to a wide variety of student interests and student backgrounds, something that would have been more difficult to achieve had I continued in the niche in which I was trained. It is rewarding to watch the personal and professional growth of my students as they undertake novel research, and I am grateful to have the freedom at my PUI to pursue these avenues.



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Navigating a rewarding obstacle course

It is very tempting to look at research at a PUI as an obstacle course. We face significant limitations on funding and time at the institutional level and beyond. Our jobs are focused predominantly on teaching and the small remainder of free time is allocated to service, committee work, research, or other scholarship. Many natural science faculty members find ourselves limited to conducting

laboratory research during the summer. Faculty members that are on contract for 9 months actually work 12 months of the year. If we can't conduct research during the summer, then it is difficult to conduct research in any meaningful capacity.

While some of these are the same challenges faced at every institution, we face additional hurdles in that we compete for the same funding sources as many large research institutions. When considering other economic disadvantages of the Appalachian region, it often feels like being the overlooked underdog. This proves especially challenging when we have ideas for exciting or cutting-edge research, but don't have the tools or support to be able to complete the work. Coupled with the relative geographic isolation of our institution, this leaves us with limited resources and large distances between us and our collaborators. While the funding situation limits what we can do financially, it also forces us to become more resourceful. As a result, undergraduate students and faculty mentors develop research projects together, without the degrees of separation that one might find at a larger institution.

For our students, all of the training and skill development is facilitated by the faculty mentor directly. This means that the student is involved in every step of the project, from conception to publication. Many students conduct their projects over the course of multiple years and mature as they develop their projects, having a strong sense of ownership. Intensive training at the beginning provides a strong foundation for students, allowing them to bloom into independent researchers with strong critical thinking skills by the end of their undergraduate careers. At our particular institution, a majority of our students are first generation college students and come from low-income backgrounds in underserved communities. The ability to nurture their growth in a one-on-one mentoring relationship directly contributes to their success in the future, ultimately supporting the longevity of our region.



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Big enthusiasm, big chances, and big payoffs

The big challenge when conducting research at a PUI is that all of your research students are undergraduates, who are full-time students during the academic year. At most PUIs the summer session is where the bulk of research is completed, as each research group has 10 or so weeks where students work full-time.

Research with students starts with a lot of teaching, and eventually pays off in research results. Many undergraduates carry these projects over into the school year, either for credit, for pay, or just because they are excited about their project. Most projects take several years to complete, and students who graduate pass on their projects to the next student. For this reason, it is advantageous to run your PUI research group like a mini-research group, and bring in students as first-year or second-year students, keeping the ones who are ignited by doing research until they graduate. This early introduction to research model allows the older students to pass on knowledge to the younger students, and keeps momentum going in the lab. What undergraduates lack in knowledge, they usually make up for in enthusiasm and work ethic. Because the pace of research is slower, faculty at PUIs have to be careful about the projects they choose if they want to publish papers and have grant proposals funded (which we do!). Most PUIs support and encourage faculty scholarship with students, and understand that productivity will be lower. One big advantage of PUIs is that you don't have to publish as much as you would at a research university, and this gives one flexibility to take some big chances with your research.



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Balancing challenges in pursuit of the most fulfilling career

There are many wonderful and fulfilling reasons to pursue a career as a science professor at a PUI. These include the a.) opportunity to support and influence young people interested in innovative science projects, b.) intellectual freedom to pursue research projects for which you are most passionate, c.) ability to work under a relatively flexible schedule, and d.) freedom to be your own “boss”.

Students who receive their baccalaureate degree from undergraduate institutions make up a disproportionate share of the people who pursue advanced degrees in science and related professions (health, law, etc.). As such, PUI professors are well positioned to make a positive impact on society by training the next generation of leaders. Science is an engine for social mobility; it is particularly important that opportunities to excel in science and to pursue science (and related) careers are available to people of all backgrounds, especially to those who hail from groups historically marginalized in science.

Individuals are attracted to science because they enjoy solving challenging problems and pursuing open-ended, discovery-based research. Scientists chose careers as PUI professors because they also value teaching, mentoring, and supporting the intellectual development of young people. One of the greatest challenges of being a PUI professor is excelling at these synergistic, yet often times conflicting, activities. Well-developed time management and focus skills are critically important for success in the academic trinity - teaching, outcome-oriented research, and service to the institution. At PUIs, the teaching loads are high, and our research students work full-time only during the summer months. As such, PUI science faculty need to have a “fire in the belly” for generating new knowledge, and that fire needs regular encouragement, i.e. teaching loads and service expectations must be balanced with regular research engagement in order to maintain momentum and productivity.

These opportunities and challenges make for a busy yet rewarding career for a PUI professor. A career filled with enormous job satisfaction as you witness the intellectual and professional development of your students. And a career filled with a strong sense of accomplishment as you work with your students and colleagues to answer and communicate important scientific discoveries through peer-reviewed publication and attainment of external funding to support research ideas.



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**Research at a PUI is all about
making a lasting impact in a short
time**

The first research experience is a pivotal moment in a student's career, particularly at a primarily undergraduate institution where students work directly with faculty. These opportunities are often their first

exposure to a real research environment and a first chance to move beyond textbook knowledge. At this early stage, a small investment of time by the mentor has an immeasurable impact on learning in the lab and perceptions about what it means to 'do research.' If a student is starting with no prior experience, then each hour in the lab is a significant part of their research career up to that point. This makes it imperative for mentors to invest some time into designing a research program that sets good habits, and to engage the researcher with a question they find interesting.

The importance of this first experience is balanced against the fact that we get a limited amount of time with students in an undergraduate lab. Students may have a few hours each week during the school year or, if we're lucky, work full-time in the lab for a ten-week summer experience. Many students are just starting to get comfortable and develop independence as they reach the end of their undergraduate degrees. This is another case where early recruiting and having a plan pays off, allowing quick integration of students into the lab. On the other hand, the shorter time scale gives faculty the freedom to try new things out and pivot to a new project in the next term.



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While challenging, undergraduate research is a valuable academic practice

Establishing and maintaining vibrant research programs are important goals for many professors at learning institutions worldwide. For professors working in primarily undergraduate student settings, achieving these goals can be fraught with a variety of challenges, many of which are unique

to working with undergraduate student researchers. In particular, student recruitment can be especially challenging, as often this involves balancing the disciplinary knowledge and maturity of a student with their year of study. As well, training undergraduate students to be researchers is typically very time intensive and usually requires a significant amount of one-on-one interaction between the professor and student. This time investment becomes even more pronounced considering the fact that most undergraduate student researchers are only employed for a relatively short amount of time before they graduate. Additionally, research progress can be quite slow due to the relatively high turnover of undergraduate student researchers. Designing undergraduate research programs with realistic, attainable, short-term milestones and modular research projects thus becomes another challenge for professors to overcome.

Despite the challenges that undergraduate research can present to professors, there also exists a number of distinct opportunities. For most students, their first experience in conducting research begins at the undergraduate level. Professors working primarily with undergraduate students are thus in a unique position to foster and develop the curiosity, inquisitiveness and enthusiasm for research many of these students exhibit. This has the potential to profoundly influence the future interests and careers of many students. In addition, the mentorship role adopted by professors in these situations often evolves into a more impactful relationship with undergraduate student researchers, which can have lasting positive impacts on both professors and students beyond the term of the research. There is no doubt that undergraduate research is challenging on many fronts. However, it remains an extremely valuable academic practice that can be immensely rewarding for both professors and students.

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