

# The Importance of Scientific Publishing: Teaching an Undergraduate How to Swim the Entire Length of the Pool

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A number of programs are currently available to support undergraduate water research. For example, many academic institutions across the United States offer undergraduate research scholars' programs. The National Institutes for Water Resources (NIWR) helps the U.S. Geological Survey (USGS) meet the nation's water needs by "...transferring the latest tools and knowledge to water professionals around the country, training the next generation of water scientists, and tackling emerging water issues in collaboration with USGS scientists." Numerous projects funded by USGS and NIWR support undergraduate research assistants throughout the states and territories of the United States. The National Science Foundation (NSF) has invested significant resources into their Research Experience for Undergraduates (REU) programs across its directorates, providing key opportunities for undergraduates to participate in summer research experiences during a six- to ten-week period. The United States Department of Agriculture National Institute of Food and Agriculture (USDA NIFA) also funds undergraduate fellowship programs in key challenge areas. Furthermore, the U.S. Environmental Protection Agency (EPA) sponsors a People, Prosperity, and the Planet (P3) Student Design Competition.

Many assume that undergraduate research projects are not capable of generating enough high quality information to publish in peer-

reviewed journals. Often undergraduates are simply acknowledged or less frequently added as lower order co-authors on papers to which they contributed. The students are often not engaged through the complete publication process. Unfortunately, this limits undergraduate students' opportunities for understanding the entire research paradigm and properly framing their contribution within existing scientific literature, until they get into graduate school. A graduate thesis is often the first major publication for a student.

Russell et al. (2007) noted that when undergraduates participate in research they increase their understanding of how to conduct research, their confidence in their research skills, and their awareness of what graduate school might be like. Linn et al. (2015) provided an in-depth review of undergraduate research opportunities, noting that past studies consistently document how students appreciate undergraduate research opportunities. However, they point out that very few studies are able to explicitly measure a student's understanding of the scientific practice or science concepts. They state that "...less than 10% of the studies validate self-reports with analysis of research products" such as presentations, reports, or publications. Having a goal to publish undergraduate research will more explicitly and thoroughly train an undergraduate to understand the scientific process, better prepare them for graduate studies, and more effectively assess undergraduate research programs.

## Outlets for Publishing Undergraduate Research

While funding does not appear to be an impediment for engaging undergraduate students in water research projects, many students never reach the publication stage. The lack of an avenue to publish this undergraduate research is a primary reason for the limited publishing. Many states and even specific universities have undergraduate research journals that typically publish articles without copyright, but their success varies based on institutional support and the dedication of a few motivated individuals. Such journals struggle with finding adequate editors and reviewers for papers, and also struggle to support published researchers because of limited readership. More opportunities should be provided by key journals in water science and engineering to foster the publication of undergraduate research, and the authors applaud the *Journal of Contemporary Water Research and Education* for providing an avenue to demonstrate the ability of undergraduate students working in the multidisciplinary fields of water resources across the United States. As evidenced by the publications in this special issue, undergraduate students, when properly mentored, can contribute significantly to the peer-reviewed literature.

## Key Strategies for Promoting Undergraduate Publishing

While the setup of undergraduate research programs can vary, an undergraduate student is typically paired with a faculty mentor to work as part of their research team, along with graduate students and postdoctoral scholars. The time frame of such experiences can be an impediment to generating enough research data or navigating through the entire research process to produce a peer-reviewed journal article. Several strategies exist to alleviate this roadblock. Of course, these strategies start with a highly motivated undergraduate student and a faculty mentor who understands the value of publishing for the student's career. The articles in this special issue of the *Journal of Contemporary Water Research and Education* serve as illustrative examples of the power of motivation and challenge the assumption

that programs such as the NSF REUs are not long enough to produce high quality, publishable research.

Many undergraduate students are simply dedicated and substantially mentored and advised to publish their research even after completing short-term research experiences. For example, *Schmidt and Lewis* explored the use of consumption-based fixed rate pricing models to balance revenue stability versus conservation during times of water scarcity. They applied the pricing models to two case studies with data from Lomita, CA and Longmont, CO. *Andy et al.* evaluated the ability of multivariate logistic regression models to correctly estimate the probability of groundwater arsenic concentrations from bedrock drinking water wells in New Hampshire. The study specifically investigated three arsenic concentration thresholds (1, 5, and 10  $\mu\text{g/L}$ ). They also investigated the benefit of including additional variables in the models such as well type and casing length. They reported that the original multivariate logistic regression models performed well in identifying local spatial variability in arsenic concentrations. Another example is *Diaz et al.*, in which the researchers compared three distinct metagenomics-based methods for assessing the presence of antibiotic resistance genes along a permafrost thaw gradient in Abisko, Sweden. Funded by the Department of Energy, the goal was also to enhance our understanding of the presence of antibiotic resistance genes in natural environments. Finally, *Alvarez et al.* describes research from a ten-week NSF REU focused on elucidating how water chemistry and iron oxidizing bacteria affect the formation of iron oxides in creeks with circumneutral pH. This research impacts our understanding of iron biogeochemical cycling. While the ten-week REU focused on data collection and analysis, a motivated undergraduate pushed the work through the publication process because of the opportunity to publish in this special issue focused on undergraduate research.

So what are potential strategies gleaned from these special issue publications that go beyond simply the requirement of a motivated undergraduate and mentor? First, design the research such that it builds upon a solid foundation

of previous work and creates an opportunity to collect significant data in an undergraduate research program. Publishing is an easier path for students with opportunities to work in laboratories funded through consecutive undergraduate scholars' programs. Previous studies specifically note that one key to successful undergraduate research is sustained as opposed to intermittent participation in research experiences (Thiry et al. 2012; Linn et al. 2015). The publication by *Vincent and Hoellein* is a prime example of this approach in which the undergraduate student worked with a faculty member for two and half years. They studied anthropogenic litter accumulation at a Lake Michigan beach in Chicago, IL, concluding that the fall season had higher accumulation rates and that infrequent sampling will underestimate total anthropogenic litter abundance.

Another option to ensure longer-term involvement is to extend the research experience by offering course credit through a research methods class or extend the research into a senior thesis or capstone project. An example of this model resulted in the publication by *Rando et al.* that focused on rapid stability assessments of lake shorelines to prioritize management. The rapid assessments include a number of metrics including shoreline bank height, bank angle, armoring, wind direction, and unconsolidated materials. Measured erosion rates generally corresponded well with the rapid assessment tool to identify locations at risk for instability and determine the most important attributes of management efforts. Similarly, the publication by *Bockwoldt et al.* was an example of sustained effort through both an initial NSF REU but also incorporating the REU research into a senior thesis at the undergraduate's home institution. The authors studied the relationship between zooplankton diversity and cyanobacteria in Lake Champlain. Cyanobacteria density was negatively correlated with phytoplankton richness, which was positively correlated with zooplankton diversity. The research concluded that cyanobacteria could directly affect zooplankton diversity and indirectly affect fish diversity.

Another strategy is to ensure that multiple summer projects overlap and/or build upon each other with co-authorship shared by multiple students. An example is the publication by

*McNichol et al.* which combined undergraduate research projects from two years of a summer NSF REU. The two students worked on similar topics conducting jet erosion tests (JETs) to quantify the erodibility of root-permeated soils but in completely different summer REU sessions. The projects built upon each other by validating the JETs compared to the more traditional flume experiments and comparing soil erodibility derived from JETs in the field. While the students finished their specific parts of the NSF REU during their own ten-week experience, they remained engaged in the research process by continuing to work as a group to determine how to merge their work, review drafts of the manuscript, respond to reviewers' comments, and review the proof of the accepted manuscript.

In *Luo et al.*, the undergraduate student shared the project with two other students in order to complete the research. These authors investigated the use of nanosheets for arsenic removal with efficiencies that approached 94% at optimal pH. Similarly, two teams of undergraduates were merged to tackle aspects of the *Elliot et al.* project funded through the US EPA P3 student design competition. They used 3D printing to design and fabricate complex media designs (spherical gyroid) for biofilters. The manufacturing and post processing of hundreds of gyroid media units required a large and committed team of undergraduate students. Their work attempted to maximize specific surface area while also providing flow refugia where biofilms were protected from fluid shear stress. The research demonstrated that 3D printing can be used for media fabrication and optimization by creating unique flow pathways through the biofilter.

Once again, we applaud the *Journal of Contemporary Water Research and Education* for providing this opportunity to undergraduate students. We hope that mentors in academia, industry, and government will share this special issue with their students to demonstrate the potential of publishing their work in this and other peer-reviewed journals.

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