The BASIL CURE Initiative: Transforming How Students Learn Biochemistry Through Real Research

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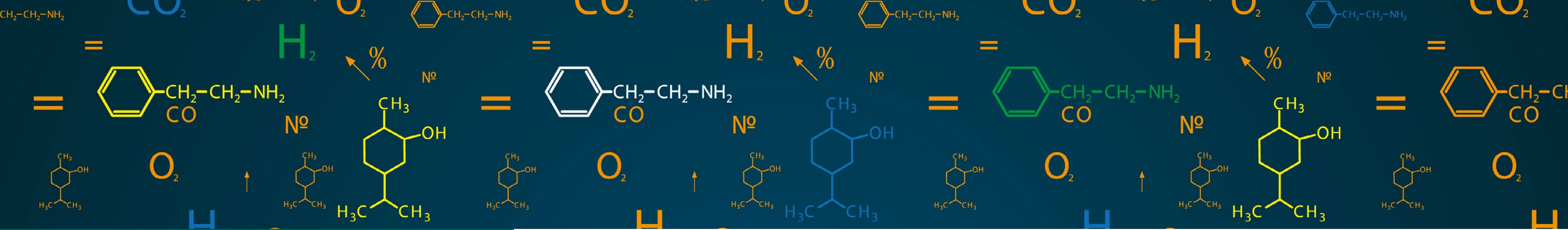


The BASIL CURE Initiative: Transforming How Students Learn Biochemistry Through Real Research

Teaching students how to think like scientists is a critical but challenging goal in biochemistry education. The Biochemistry Authentic Scientific Inquiry Lab (BASIL) initiative was conceived by Dr Paul Craig from the Rochester Institute of Technology and is led by colleagues across multiple institutions. They have developed an innovative curriculum that transforms traditional cookbook-style laboratory courses into authentic research experiences, also known as a Course-based Undergraduate Research Experience (CURE). By investigating real proteins with unknown functions, students learn essential scientific skills while expanding our knowledge of protein biochemistry.

From Research Lab to Teaching Lab

The story of BASIL began in a research laboratory where students were using computational and experimental methods to predict protein functions. In 2004, students at Rochester Institute of Technology developed software tools to help visualise protein structures and identify potential enzyme active sites – the specific parts of proteins where chemical reactions occur.

As students worked with these tools to study proteins of unknown function, Dr Craig and his colleagues noticed something remarkable. The students weren't just following instructions – they were developing critical scientific thinking skills. They began asking their own questions, forming hypotheses, and designing experiments to test their ideas. Most importantly, they wanted to move beyond computational predictions to actually testing their ideas in the laboratory.

This sparked a realisation: this type of authentic research experience could be adapted for teaching laboratories to benefit many more students. In 2014, Dr Craig presented the concept at the American Society for Biochemistry and Molecular Biology meeting, attracting additional collaborators, including Dr Mike Pikaart from Hope College and Dr Rebecca Roberts from Ursinus College. With support from the National Science Foundation, they formally launched BASIL in 2015 with a team of educators from seven different institutions.

The Challenge of Unknown Proteins

While we know the DNA sequences of many organisms and can identify their genes, we still do not know what many of the proteins encoded by these genes actually do. In fact, there are thousands of proteins in scientific databases whose structures have been determined but whose functions remain mysterious. This creates a perfect opportunity for student research – there are plenty of genuine scientific mysteries to investigate, and any discoveries could contribute to our understanding of biochemistry.

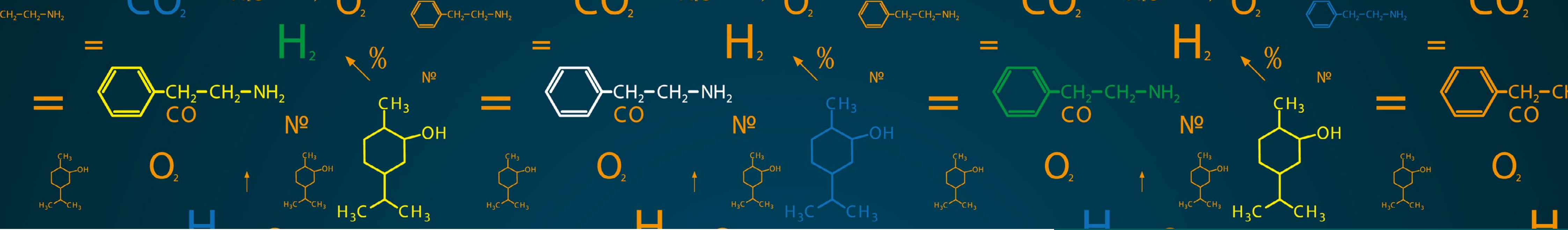
BASIL takes advantage of this situation by having students investigate these unknown proteins. The curriculum consists of eleven core modules – five computational and six experimental – that guide students through the process of predicting and testing protein functions. This mirrors how actual biochemistry research is conducted, giving students an authentic research experience.

From Computer to Laboratory

The BASIL experience typically begins with computational analysis. Students learn to use sophisticated software tools that help them analyse protein structures and predict possible functions. They start with sequence alignment tools to compare their protein's sequence to databases of known proteins, looking for similar sequences that might suggest a function. They also identify protein families and domains that could provide clues about function.

Another key tool is active site alignment of the query protein (structure of unknown function) with well-annotated protein structures in the Protein Data Bank. This analysis, along with molecular docking studies, helps students predict how a protein might interact with potential target molecules. Students can simulate whether their protein might be able to bind to and modify various biological molecules, generating hypotheses about the protein's function.

After developing predictions using these computational tools, students move to the laboratory phase. Here, they learn to produce and purify their protein of interest using techniques like bacterial protein over-expression and chromatography. They then conduct experiments to test whether their predictions about the protein's function are correct.



Dr Rebecca Roberts explains that this combination of computational and experimental work helps students understand how modern biochemistry research actually happens. They learn that science isn't about following a recipe to get a known answer but rather about using various tools and techniques to solve genuine mysteries.

Flexibility for Different Settings

One of BASIL's key strengths is its flexibility. Dr Bonnie Hall emphasises that instructors can adapt the curriculum to fit their specific needs and resources. Some focus solely on the computational aspects, while others emphasise laboratory work. The modules can be used in different orders or combinations, with additional modules constantly under development. The curriculum has been successfully implemented in settings ranging from small liberal arts colleges to large research universities, and even in some high schools.

This flexibility proved particularly valuable during the COVID-19 pandemic. When campuses shut down in 2020, Dr Arthur Sikora from Nova Southeastern University led the development of online versions of the laboratory modules. These adaptations allowed students to continue their research projects remotely, analysing real data and making scientific discoveries from home.

The team created interactive simulations and decision trees that helped students learn to troubleshoot experiments and interpret results, even when they couldn't be physically present in the laboratory. For example, they developed modules based on Google Forms that walked students through experimental procedures, requiring them to make decisions at each step and providing feedback on their choices.

Measuring Educational Impact

The team has carefully studied how well BASIL achieves its educational goals. Dr Stefan Irby, while working with Dr Trevor Anderson at Purdue University, developed sophisticated tools to assess student learning. They identified key learning outcomes and created surveys to measure students' knowledge, experience, and confidence in various aspects of biochemical research.

Their research showed that students made significant gains in their understanding of both computational and experimental techniques. More importantly, students developed greater confidence in their ability to design experiments, analyse data, and think like scientists. Even during the pandemic, when some modules had to be taught remotely, students still showed significant improvement in these areas.

Dr Erika Offerdahl at Washington State University is studying how BASIL is implemented at different institutions. Her research revealed that while instructors faced various challenges in implementing the curriculum – from technical issues to time constraints – they remained enthusiastic about its benefits for students. The collaborative nature of the BASIL community helped instructors overcome these challenges through shared resources and regular video conferences.

Embracing New Technologies

The BASIL team continues to evolve and expand their approach to keep pace with rapid developments in biochemistry. Dr Hall is leading efforts to incorporate artificial intelligence and machine learning tools that are revolutionising how scientists predict protein functions.

One major development has been the integration of AlphaFold and RoseTTAFold, powerful AI systems that can predict protein

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structures with unprecedented accuracy. These tools have generated structural predictions for millions of proteins, creating new opportunities for student research. Dr Jon Dattelbaum at the University of Richmond and Dr Steve Mills at Xavier University, along with other team members, are also incorporating tools like FoldSeek, which can rapidly search these new structural databases to identify similar proteins.

Machine learning is also being applied directly to protein function prediction. The team is evaluating emerging AI/ML tools that use advanced algorithms to suggest possible protein functions. These new tools are being carefully integrated into the curriculum to ensure students understand both their capabilities and limitations.

Impact Beyond the Laboratory

Perhaps the most significant impact of BASIL is how it changes students’ understanding of what science really is. Rather than simply learning techniques, students experience the excitement and challenges of real scientific research. They learn to deal with uncertainty, troubleshoot problems, and persist when experiments don’t work as expected.

The BASIL team is working to make their curriculum more accessible to a wider range of institutions. They are developing partnerships with historically black colleges and universities (HBCUs) and minority-serving institutions (MSIs), offering workshops and support to help implement the curriculum in diverse settings. Dr Julia Koeppe from SUNY Oswego has led workshops at institutions like Fayetteville State University and the University of Puerto Rico San Juan. Dr Ashley Ringer McDonald at California Polytechnic Institute San Luis Obispo and Dr Hall lead efforts to ensure their protocols and materials are freely accessible to all. These materials are available online at https://basilbiochem.org and have been adopted at over 50 institutions worldwide.

The team has also created opportunities for students to share their discoveries through Proteopedia (https://proteopedia.org), an online platform for sharing information about protein structures. This allows students to contribute their findings to the broader scientific community and see how their work fits into the larger picture of biochemical research. Some students have even presented their findings at scientific conferences or continued their projects as independent research.

Building a Sustainable Future

As BASIL continues to grow, the team is focusing on sustainability. They’ve established committees focused on assessment, communication, data management, instructor support, module development, and curriculum adoption. They’re working to ensure that when the original team members transition toward retirement, new leaders will be ready to take their place and continue evolving the programme.

The team is also developing more robust online resources to support remote and hybrid learning, informed by their experiences during the pandemic. They’re creating new modules that incorporate artificial intelligence tools while maintaining the core focus on authentic scientific inquiry and discovery.

As biochemistry and molecular biology continue to evolve, so too will BASIL. The team’s commitment to flexibility, accessibility, and authentic scientific experiences ensures that this innovative approach will continue to transform how students learn about and engage with science. Through BASIL, students aren’t just learning about science – they’re becoming scientists, contributing to our understanding of the molecular machinery that powers life itself.

MEET THE RESEARCHERS

Dr Paul A Craig
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Dr Paul Craig obtained his BS in Chemistry from Oral Roberts University in 1979 and his PhD in Biological Chemistry from the University of Michigan in 1985. Following postdoctoral research at Henry Ford Hospital, he worked as an Analytical Biochemist at BioQuant before joining the Rochester Institute of Technology in 1993, where he is now Professor of Chemistry. His research spans biochemistry education, molecular visualisation, and protein function prediction. Dr Craig has pioneered innovative approaches to undergraduate biochemistry education, including the development of computational tools and course-based research experiences. His contributions have been recognised with numerous awards, including the 2018 ASBMB Award for Exemplary Contributions to Education and the 2017 Chemical Pioneer Award from the American Institute of Chemists. He is transforming biochemistry education through the integration of computational methods and authentic research experiences.

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Dr Julia R Koeppe
State University of New York at Oswego, Oswego, NY, USA

Dr Julia Koeppe obtained her BS degree in Chemistry from Hope College in 2001 and her PhD in Chemistry from the University of California at San Diego in 2006. Following postdoctoral research at Oxford University, she joined the Chemistry Department at Ursinus College before ultimately joining the faculty at the State University of New York at Oswego in 2016, where she is now Associate Professor of Chemistry. Her research focuses on protein interactions that regulate blood clotting and the complement system, protein function prediction, and biochemistry education. Dr Koeppe has contributed to innovative approaches in biochemistry education, including the development of course-based research experiences.

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Dr Bonnie L Hall
Grand View University, Des Moines, IA, USA

Dr Bonnie Hall obtained dual BS degrees in Chemistry and Biology from Eastern Washington University in 1990 and her PhD in Biochemistry and Molecular Biology from the University of California at Davis in 1994. After completing postdoctoral research at the University of Utah, she ultimately joined the faculty at Grand View University in 2013, where she is now Associate Professor of Chemistry. Her research focuses on protein function prediction, enzyme engineering, and the application of machine learning to address challenges in biochemistry. Dr. Hall is committed to advancing biochemistry education by integrating novel computational tools and authentic research experiences into course-based learning, transforming how students engage with the field.

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Dr Rebecca Roberts
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Dr Rebecca Roberts obtained her BS in Biochemistry & Molecular Biology from Clark University in 1991 and her PhD in Molecular and Cellular Biology from the University of Massachusetts at Amherst in 1998. Following postdoctoral research at Harvard Medical School, she taught at Carleton College for a year before joining Ursinus College, where she is now Professor of Biology. Her research has focused on natural and environmental hormonal regulation of protease activity in mouse models of disease. Dr. Roberts is an expert in biochemical education and provides training and support to faculty on how to engage and assess their students in course-based research experiences. She is a founder of BASIL.

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