PERSPECTIVE

EXPLOITING AN INTERDISCIPLINARY APPROACH USING UNDERGRADUATE RESEARCH

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INTRODUCTION

Coming out of high school, I chose to pursue a career in chemistry on the basis of it being regarded as the "central science". My logic was that if I wanted to change directions, I could easily go into geology, biology, or physics. I knew from an early age that I wanted to go into science for the purpose of doing research, so going to university to pursue a career in chemistry seemed an obvious choice. As a child, I observed that I tended to learn things best by trying to connect new knowledge to things that I already knew, and topics with a "hands-on" component were particularly appealing. What I did not count on, however, was falling deeply in love with chemistry, which was further cemented by my experiences in research, a stint in the chemical industry, and other opportunities to apply bench craft to new challenges. What came as an even larger surprise was that microbiology turned out to be an exciting outlet that would prove to be every bit as rich and interesting as chemistry and that my background in laboratory work and chemistry would serve as a catalyst to further enhance my appreciation of other disciplines. As an undergraduate, my research experiences in both fields altered my way of thinking and the way in which I approach science. I started my university career in the United States majoring in chemistry at a fairly large institution. Two of my professors strongly encouraged me to seek out undergraduate research opportunities and to get involved in education rather than being a passive element in the process of higher education. Heeding their advice, I sought out other opportunities to further my scientific knowledge which turned out to be one of the best things that I could have done for my scientific career.

One problem in pursuing an education in the sciences is the risk of over-specialization; there is an old adage that states that all problems look the same when you are only given one way of approaching problems. Fortunately, a diversity of experiences in different types of professional labs as an undergraduate has shaped my interdisciplinary approach towards tackling research problems while giving a diverse skill set with which to take on new problems. In my 8 years as an

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undergraduate, I have done stints working in two different research groups in organic chemistry, two groups in microbiology, and a three and a half year stretch working as a lab technician in the chemical industry, as well as two years working in a clinical lab. While this may be quite extreme, I strongly believe that even a few limited interdisciplinary adventures can greatly benefit anyone that is serious about a career in science.

When it comes to enriching your education, there are lots of options, most of which provide excellent opportunities to advance your knowledge, enhance your ability to communicate science, or give back to the community. It has been my experience, both personally and now as someone in charge of supervising the research work of others, that real laboratory experience puts you ahead in terms of laboratory performance (i.e. actually standing at a bench and doing science). Here I will go through some of the lessons that I learned being an undergraduate involved in research and cross-sectorial activities that I feel really enhanced my abilities at the bench as I further explore the intersection of chemistry and microbiology.

PACKING YOUR TOOLBOX USING AN INTERDISCIPLINARY APPROACH

One of the analogies that were frequently used in my undergraduate education in the U.S. was the “toolbox”. I used every opportunity to learn as many techniques, whether “soft” skills or more specialized methods, as possible and try to apply them to new situations. This is particularly relevant when you are transferring skills from one field of research to another. Over time, I found that this interdisciplinary approach was exceptionally useful and rewarding. Being able to use old knowledge and techniques to acquire new knowledge and solve problems is incredibly rewarding.

Beyond having an interdisciplinary approach, cross-sectorial training is also a highly valuable experience. There is more than one way to do science and the ultimate focus of that science very much informs the way in which day-to-day operations are approached. Experiencing the way a clinician approaches science is often very different from the way someone working in an industrial field would.

The most often used piece of my kit that I picked up somewhere along the way is a little mental experiment called “the truck test”. The truck test posits a simple question: could someone pick up and carry on your work from this given moment if you got run down by a truck? The degree of success to which you can answer this question revolves around several soft skills that I have found often go unaddressed in undergraduate (and often graduate) settings. Traditionalists often tote the utility of the laboratory notebook as a tool for reproducing exactly what you have done. Unfortunately, your experiment is more than just what you were doing; it is highly informed by the matrix in which you were doing it.

WHY DO UNDERGRADUATE RESEARCH?

During my undergraduate work in the U.S., I and many others routinely heard about why we should do undergraduate research. Professors often proclaimed that having research on your resume could make or break an application to a graduate program. While this certainly caught the ears of many students thinking about highly competitive careers as a medical doctor or pharmacologists, selling these opportunities to those bound for careers in science seemed to relegate doing science for the sake of science to the back burner. The traditional rationale for doing undergraduate research often includes benefits such as the following:

- Resume building
- Networking
- Money
- Class credit
- Publications
- Letters of recommendation

All of these are nice, but much of this has very little to do with standing at the bench and doing actual science (which did not deter me from getting involved at the earliest opportunity!). I went into science to do science rather than chasing a career with a large paycheck attached to it. In my mind, the real benefits of doing undergraduate research really have to do with why you are presumably studying science in the first place: to learn to do actual science while being tied to a lab bench. Part of doing science is venturing into the darkness of the unknown and trying to figure out what the room looks like and how stuff works.

I am a firm believer that we learn by doing; thus, the best way to learn how to become a scientist is to do science. Working at the bench with a more accomplished master is a fantastic way to learn techniques, carefully plan, and execute experiments, and interpret the results to answer questions and hopefully ask new questions. Some of the often overlooked reasons to pursue undergraduate opportunities include the following:

- Cycle of science (the “real” scientific method)
- Confidence
- Bench skills
- Quality control and streamlining
- Data and project management
- Innovative problem solving
- Communication of scientific concepts
- Cultivating curiosity

THE CYCLE OF SCIENCE

As it turns out, the daily grind of science is quite different from the pre-programmed laboratory experiments that you are exposed to in your general course work or the nicely displayed algorithms of the scientific method. One of the biggest takeaways from my undergraduate research experiences is mastering the workflow of real laboratory work and that successfully applying the scientific method requires a good deal of creativity. In many ways, the analogy of a craftsman and an apprentice fits quite well.

In undergraduate laboratory exercises, more often than not in my experience, a lot of the thinking and preparatory work has been done for you. Procedures are often step-by-step and have been fined-tuned to a degree of precision that leaves no room for actual "discovery". In real life, the flow of a research project has a "tick-tock" type rhythm whereby the results of one round of experiments directly informs the design of the next set of experiments.

Furthermore, most if not all of the preparatory work has been done for you in advance: plates have been poured, reagents are ready to use, and instruments are in working order and ready to use. This creates the illusion of ease because in the real world, it is unlikely that things are to be in such a state that you can simply walk into the lab and walk out with publishable results. The amount of preparation that goes into executing actual experiments can often take longer than the experiment itself.

When I started my research in Iceland, no one had touched one of the HPLCs in years and no one knew how to operate the new one. Fortunately, the three and a half years that I spent in the chemical industry as an intern lab technician (tied to the HPLC and GCs) taught me everything that I needed to know to strip down an HPLC and get it running in short order. This gave me a tremendous advantage to carry on with my own research projects while supporting the on-going work of researchers in other groups.

CONFIDENCE

The psychological benefits of being professionally active during your undergraduate training are not to be underestimated. Building up your self-confidence to tackle complex, new, and highly involved research projects is critical to your ability to successfully execute laboratory operations. Furthermore, having a track record including a number of failures is also important as it demonstrates that not only is botching a procedure okay, it is often part and parcel of the day-to-day grind of doing research. Even after only having worked a few months one summer in a research lab radically altered the way that I approached standard coursework. As I have transitioned more towards a teaching role, I continue to find that students that engage in research early on in their careers are often much more capable when it comes to tackling their later coursework efficiently as well as conducting actual work with a high degree of reproducibility.

DATA AND PROJECT MANAGEMENT

One of the lessons that you learn from working on a research project is how to manage the planning and execution of a project as well as keeping data organized in such a way that it is actually useable. Without a lot of prior experience, it is easy to become overwhelmed with the scope and interrelatedness of a series of experiments and end up dropping the ball due to disorganization. While the use of laboratory notebooks receives a tremendous degree of credit, in the electronic age, a lot of your data is captured electronically in Excel worksheets or other formats. At least in my experience, data sets in "real world" research projects tend to be quite large with measurements from multiple instruments over time needing to get kept in order. An extremely useful strategy for dealing with the inflow of data is to design an Excel sheet in parallel while designing the experiment. Furthermore, working with an outline of the report or manuscript and plugging in data and discussions as you go rather than handling data after the fact can be a very efficient way of working with a data set.

COMMUNICATION OF SCIENTIFIC CONCEPTS

Stepping out of the classroom and into the real world of research showed me that scientific writing comes in more flavors than producing reports and scientific articles. In order to be an effective scientist, writing for different audiences is a skill that must be thoroughly mastered. An often overlooked backdoor route to improving your scientific communication skills is to carefully dissect the work of others. This has the advantage of being something that you can start early in your career before you know much of anything but can still be of use even if it is catching a potentially embarrassing grammatical error. Early in my career, tearing apart manuscripts prior to submission was a favorite past time among those in the research groups with which I was involved. When I transferred my focus more towards the biological, I found that my background in chemistry and having English as a native language was very helpful with improving the manuscripts of other more advanced researchers. At some point, revising the work of others lead to conversations regarding ways to improve experimental designs or upgrading methodology to be higher throughput or more robust which eventually lead to my first few co-author credits.

One of the aspects of real-world science that I found most surprising was the grant writing process. I had the (mis)fortune of becoming involved in writing applications for several ideas that I had while I was still an undergrad. The amount of time that goes into constructing well-thought-out grant proposals can typically run into the hundreds of man hours depending on the size of the application and the number of people involved. Thus, learning how to effectively multitask while managing the contributions of others is absolutely essential. One aspect of communicating science was how to organize your ideas into do-able units which are often referred to as "work packages" consisting of well-defined tasks and subtasks. Writing grant proposals that are reviewed by experts and non-experts alike requires careful balance. My earliest experiences writing grant applications were an abysmal failure: I found it difficult to overcome the formal, highly technical writing style that was drilled into my head. After several rejections and heeding the careful comments of peer-review, I started to have more success as I moved through my undergraduate career. Furthermore, writing up your scientific work to be broadly understood by the public is another highly valuable writing skill.

Another often under-emphasized aspect of communicating your scientific work, either verbally or in writing, to the broader public. Effectively communicating the importance of advanced science to laymen with little or no scientific training presents a tremendous challenge. I have found that a good place to start is by talking to friends about your work in such a way as they do not lose interest. This can often be accomplished by talking about the broader implications and impacts of your work. Understanding the impacts of your own work are also of great importance when going before an opponent critically reviewing your thesis work or when an application for funding is being scrutinized by a panel of experts. Another potential target to practice your communication skills include younger school children. While this often involves a healthy degree of generalization and making analogies to things with which can be related to everyday life, I have often found that if you can adequately explain a scientific concept to a 5 year old, you can probably effectively communicate it to anyone else.

Learning how to communicate visually with effective figures is often a highly useful skill. While data visualization is a topic all by itself, taking the time to explore a few entry level texts (refer to the Further Reading section) can be rewarding. For instance, showing the interrelationship between tasks with a simple flow chart can add clarity to complex experimental designs and quickly confer the just of what you are doing to a reader.

BENCH SKILLS

Standing (or sitting) at a lab bench and performing tasks is the bread and butter of working in a laboratory in any context. While the individual techniques and practices that you learn may ultimately have value, the real benefit stems from your ability to rapidly assimilate a new methodology and put it into practice. I found that having a broad base of analytical techniques to choose from really enhanced my work.

As you spend more time at the bench, you will observe that laboratory life is like a small ecosystem unto itself and one of the most useful elements that I gained from being involved in professional laboratories was becoming attuned to the heart beat of the lab. In many ways, any lab is like an ecosystem with an inflow of consumables and an outflow of data and waste. Furthermore, each piece of equipment has its own "vital signs" and becoming attuned to the needs of each piece of equipment is a lot like the dating process. Many weekends of being alone in the lab troubleshooting instrument problems became a somewhat regular phenomenon. Learning to listen to equipment's "vital signs" is often a good place to start. Being attuned to what something is "supposed to sound like" can often quickly alert you to something being wrong.

Developing solid troubleshooting skills can save costly visits from instrument specialists as well as greatly reduce unnecessary downtime. During slow moments, I often found it useful to flip through the "troubleshooting" and "maintenance" sections of instrument manuals. Also, learning how to keep equipment in proper working order by following a regular maintenance cycle can often prevent problems, especially since many consumable parts wear out in a predicable fashion with regular usage.

DEVELOPING A STREAMLINED APPROACH AND QUALITY MANAGEMENT

During the "undergraduate era" of my career, which spanned clinical, research, and industrial labs, I noticed that turnover had a profound effect on efficiency. Every time that one of the more senior members of a research group left it was like cutting off an arm. Most of the time, it was just basic routine tasks that suffered most, not to mention the specialized knowledge that seemingly evaporated overnight. Highly efficient enterprises (like multinational corporations) tend to treat people like replaceable cogs and have a system in place to deal with retaining knowledge. In my experience, this is something that research groups do quite poorly. Larger research groups seem better able to maintain some sort of procedural continuing while the loss of a senior member in a small research group is devastating. Re-inventing the wheel can be costly and laboratories performing the same tests as other labs need to be able to demonstrate that they get comparable and highly reproducible results. In an industrial lab, especially one that operates a quality management system (QMS) such as ISO 17025 or ISO 9001, commonly performed procedures have a high degree of standardization; procedures are written and made centrally available. While QMS topics often illicit groans from academics, I learned firsthand their efficacy which was further confirmed as I put lessons from QMSs into practice in my own research.

While ISO is often considered to be too paper heavy for research groups that need to maintain a high degree of fluidity, some of the major concepts can and should be readily integrated into your daily work. ISO principles include using a process approach, systematic approach to management, striving for continual improvement, and taking a factual approach to decision making. Key concepts within these principles are particularly relevant such as maintaining traceability, good records keeping, document control, and employee training.

Standard operating procedures (SOPs) maintained by one person can easily be disseminated to new hires or visiting researchers. Having a system for routine procedures saves time and often money. I have found that having bottles for individual assays or media components with labels that include dummy-proof directions are a fantastic way to go. Not only does it take the guess work out of preparing reagent solutions, the directions are right in front of you. As it turns out, reproducibility problems are the Achilles heel of experimental results. Thus, developing good quality control practices, even in a research setting, is absolutely vital to ensure that you are producing trustworthy results.

Fortunately, you do not need to have completed any education to start filling the gaps without much experience in quality management. After spending a few years working in the chemical industry, I found that my awareness of these procedural gaps was heightened and all that you really need to do is recognize the need to fill a gap. As someone with experience with a particular method, you can start writing SOPs and specific methods yourself and make them centrally available to your group. I have observed countless times in my work in research labs so-called “procedural drift” whereby a specific procedure is passed down from senior researcher to new inductee, who will then transfer their version of a procedure to someone in the future. This can result in large deviations in practice and often result in disastrous mishaps costing valuable time and deteriorating the quality of the output result.

You can similarly apply the creation of standardized documentation for standard control charts or reagent logbooks. Not only will this make life easier for your supervisor, it will help those that come after you more quickly adapt to their new surroundings while making it easier to catch instrumentation problems or operator errors. An added benefit of taking the initiative writing procedures and creating standardized forms is that you can build your own personal repertoire of methodologies. Over my career to date, I have written dozens upon dozens of such procedures adapted from the scientific literary, crafted de novo, or “borrowed” and adapted to my own liking. This gives you a tremendous degree of power and you can easily pass this knowledge to a colleague in need with a few mouse clicks. A common topic within many QMSs is continuous improvement. As you begin to develop your own SOPs and systematic documents, you can also improve them based upon flaws or amended ways of doing things.

Aside from the ISO quality management systems, there are many other quality management systems that may be more relevant to the constantly evolving environment you find in research. A background in Good "Anything" practices (GxP) such as Good Manufacturing Processes (GMP), Good Laboratory Practices (GLP), or Good Clinical Practices (GCP), will serve you very well as you move through your coursework, practical training, or first stint in a research lab. Despite having different names, many of the practices in GMP, GLP, and GCP share many commonalities.

INNOVATIVE PROBLEM SOLVING

Innovation is not just a business buzzword; it describes ways of thinking in terms of problem solving with limited resources. Doing research with limited resources, while challenging, is rewarding. The reality of science, at least as I have experienced it thus far in my career, is that you never have "ideal" conditions to do the work that you want. You might be missing a piece of equipment or full funding for a particular project, or extra pairs of hands. Stated more succinctly, you have to make do with what you have or can easily get your fingers on. Fortunately, this is something that time at the bench as an undergraduate can quickly teach you how to deal with using a bit of innovation and problem solving.

Having to deal with equipment on a daily basis, I quickly learned that being well acquainted with instrument manuals and having a supply of texts on specific techniques to be an excellent first line of defense to dealing with problems. Instrumentation, whether in a lab with a chemistry focus or a biological one, is absolutely critical to being able to consistently turn out quality results. Instrument downtime is an absolute killer of efficiency. In order to avoid downtime, not only should you learn the ins and outs of your equipment, you should get into the practice of learning preventative and routine maintenance procedures. I found time and again that maintaining a pool of spare parts, whether it be replacement consumables parts of an HPLC's pumps or on occasion, asking around for spare parts and solutions is a cost-effective solution and can also serve as a catalyst for professional networking. But when all else fails, you must sometimes rely on your wits to solve problems especially when replacement parts are weeks away or there is no money in the lab's budget for a service call.

The basis of all problem solving skills is a combination of highly disciplined and systematic step-by-step investigations into a problem with a bit of innovation thrown in. When I first moved to Iceland, my background was mostly in chemistry. Two of the first major challenges I faced in working in a microbiology lab involved patching together a water distiller with a cracked boiling housing and resuscitating a mistreated HPLC. As both pieces of equipment were absolutely vital to doing any sort of microbiology, I got to work. The cracked boiler housing was a bit of a challenge. I decided to try carefully applying electrical tape, which is reasonably heat resistant. Much to my surprise, it worked and the boiling chamber actually managed to run nearly continuously until the electronics failed a number of years later. Coaxing the HPLC back to working order, on the other hand, required several weeks of methodical troubleshooting. The biggest tell that there was a problem in the first place was incredibly high back pressure (in excess of

40 MPa!) at only 10% of the recommended flow rate. Unfortunately, there was no "log book" detailing the instrument history so I started by patiently unraveling the history of the instrument, who had used it, and when the problem started. I slowly and patiently worked the problem backwards by eliminating one variable at a time only to find out that a series of problems was to blame. Upon the instrument's initial installation, the wrong diameter guard column had been installed and the steel tubing had been kinked by a careless technician. To make matters worse, someone had injected unfiltered biological samples onto the column.

Learning how to maintain, repair, and keep equipment in working order all represent a highly valuable transferable skill. Once you learn how to keep one piece of equipment in order, adding another is less of a mystery. It has been my observation that hiring managers, whether interviewing to fill a research job or a job in the private sector, tend to value these types of transferable skills over an applicant's ability to perform specific procedures. By paying close attention to parallel disciplines, you can often transfer ways of handling science to your own work. Furthermore, by diversifying your work experience by venturing into an industrial or clinical setting, you can gain valuable insights into areas such as quality management which are often neglected in research.

CULTIVATING CURIOSITY THROUGH INVOLVEMENT IN INTERDISCIPLINARY STUDIES

Beyond developing transferable competencies, the opportunity to do research at the undergraduate level also allows you the rare opportunity to explore your own interests beyond the highly pre-programmed nature of the vast majority of undergraduate work. I found that I naturally gravitated towards organic chemistry as a discipline while enjoying related aspects in the fields of biochemistry and microbiology. As it turns out, the intersection of these disciplines is incredibly fascinating and acted as a catalyst for my further learning.

While I was in my initial undergraduate period, I had stumbled across a few papers by George Whitesides in which he used enzymes as catalysts for organic synthesis. This planted the idea in my head and I caught on fire. As a result, I decided to dual major in biology; at that time, green chemistry was up and coming and had not reached the level of awareness that it currently enjoys. While the use of enzymes in niche applications including in food processing, textiles, and organic chemistry, to name a few.

While standing at the bench in a research lab as an undergraduate will often reinforce the lessons taken from your course work, it is also a fantastic opportunity to go beyond the book and expand upon your own intellectual curiosity.

APPRECIATING NATURE'S ORGANIC CHEMISTS

Going through undergraduate coursework, I could not help but stand in awe of the great synthetic masters such as Karl Fisher, Whitesides, and E.J. Corey. Their insights into the way that molecules behave are nothing short of a marvel of our species'f ability to understand. At some point, however, I came across a quotation from Francois Jacob that goes as follows:

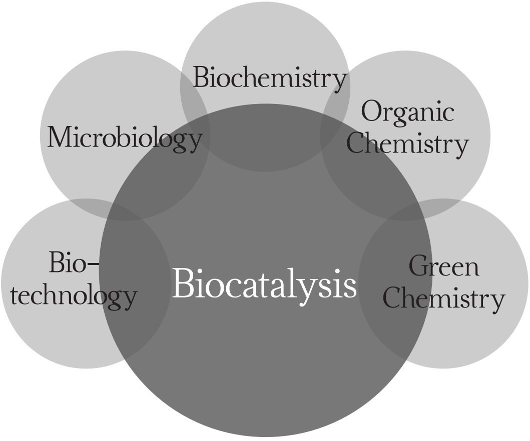
> *Nature is a tinkerer, not an inventor*

Table 1. Green chemistry (adapted from references 1 & 2)

Green Chemistry Principle	Traditional Synthesis	Biocatalysis
Prevent waste	X	✓
Maximize atom economy	X	✓
Minimize toxicity	X	✓
(preserve functionality/efficacy)	X/✓	✓
Minimize auxiliary substances	X	✓
Minimize energy input	X	✓
Renewable feedstocks	X	✓
Minimize protecting group usage	X/✓	✓
Use catalysts	X/✓	✓
Design for biodegradability	X/✓	✓
Real-time analysis	✓	✓
Minimize accidents	X/✓	✓

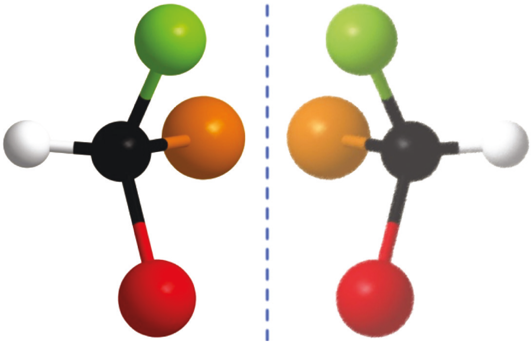
As it turns out, nature has been at the synthesis game a lot longer than we have been on the scene. Biochemical reactions have been around on this planet for at least 3.5 billion years, and evolution has spent millions and millions of years fine-tuning numerous reactions to specific conditions ranging from highly saline and icy cold to well beyond the boiling point of water. Not surprisingly, enzymes are highly efficient catalytic systems given this protracted development time. To put their efficiency in perspective, a typical catalyst for a reaction uses between 0.1 to 1 mole percent (2). Enzymes on the other hand, can catalyze reactions in the range of 10^{-3} to 10^{-4} mole percentage! Fortunately, we are not limited to "natural" reactions. Many enzymes will accommodate other substrates, a trait commonly referred to as enzyme promiscuity.

Figure 1. Biocatalysis is a multidisciplinary field calling on many other disciplines



Biocatalysis is a broad and highly-interdisciplinary field (Fig. 1) that looks at the use of living systems, in part or in whole, to perform reactions. Thus, the whole gamut from cultures of microbes, crude extracts, to purified enzymes can be used in various applications. Biocatalysts have traditionally been touted for their high catalytic efficiency, mild operating conditions, high selectivity (chemo-, stereo-, and regio-selectivity), immobilization, and biodegradability. Their drawbacks, however, are likely the

Figure 2 Enantiomers are moleculer mirror images

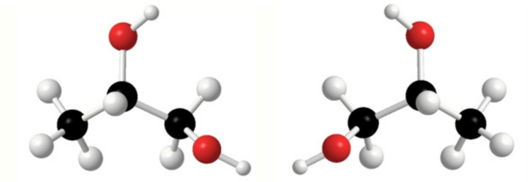


reason for their relegation to specialized roles; enzymes are frequently prone to inhibition phenomena, cofactors, solvent compatibility, lack of commercial availability, and their selectivity. For these reasons, talk of the use of biocatalysts is frequently regarded with suspicion and viewed as a black box due to the complexity of working with living organisms or parts thereof.

With the push for "greener" chemistry and industrial practices, however, the use of biocatalysis in many applications is beginning to gain a foothold. Of the commonly cited twelve principles of green chemistry (Table 1) originally put forth by the EPA, biocatalysts are capable of being compatible with all twelve principles.

Microbes provide a vast library of enzyme chemistries just waiting to be explored. Given their ubiquitous nature and adaptations to broad environmental conditions, they are a potential treasure trove. One particularly interesting aspect of enzymes is their inherent stereopreference opening the doorway for their use as chiral catalysts in synthetic applications.

Figure 3 – 1,2-propanediol and its two enantiomers. Note the difference in configuration at C2



CHIRALITY: THE HANDEDNESS OF LIFE

While taking organic chemistry, I became enamored with the "handedness" of life which I found to be a bit of an abstraction at first. Chirality (Greek for "handed-ness") is of fundamental importance in the biological sciences and poses a number of serious problems in organic synthesis. Enantiomers are stereoisomers that are mirror images of one another (as shown in Fig. 2) whereas diastereomers are stereoisomers that are not mirror images of one another.

Most biomolecules have inherent chirality yet we take this for granted. Sugars typically have multiple chiral centers. At some point during my long undergraduate tenure, I took an interest with 1,2-propanediol (1,2-PD, Figure 3). This three carbon diol has a single stereocenter at C2 and thus exists as two enantiomers. While being an extremely simple molecule, separating the two enantiomers of 1,2-PD is incredibly challenging and caught my attention.

EXPLOITING THE CHIRALITY OF ENZYMES

Enzymes, being proteins, are composed of L-amino acids. As such, enzymes are highly specialized organic chemists that often demonstrate chiral preferences and in many cases can accept non-

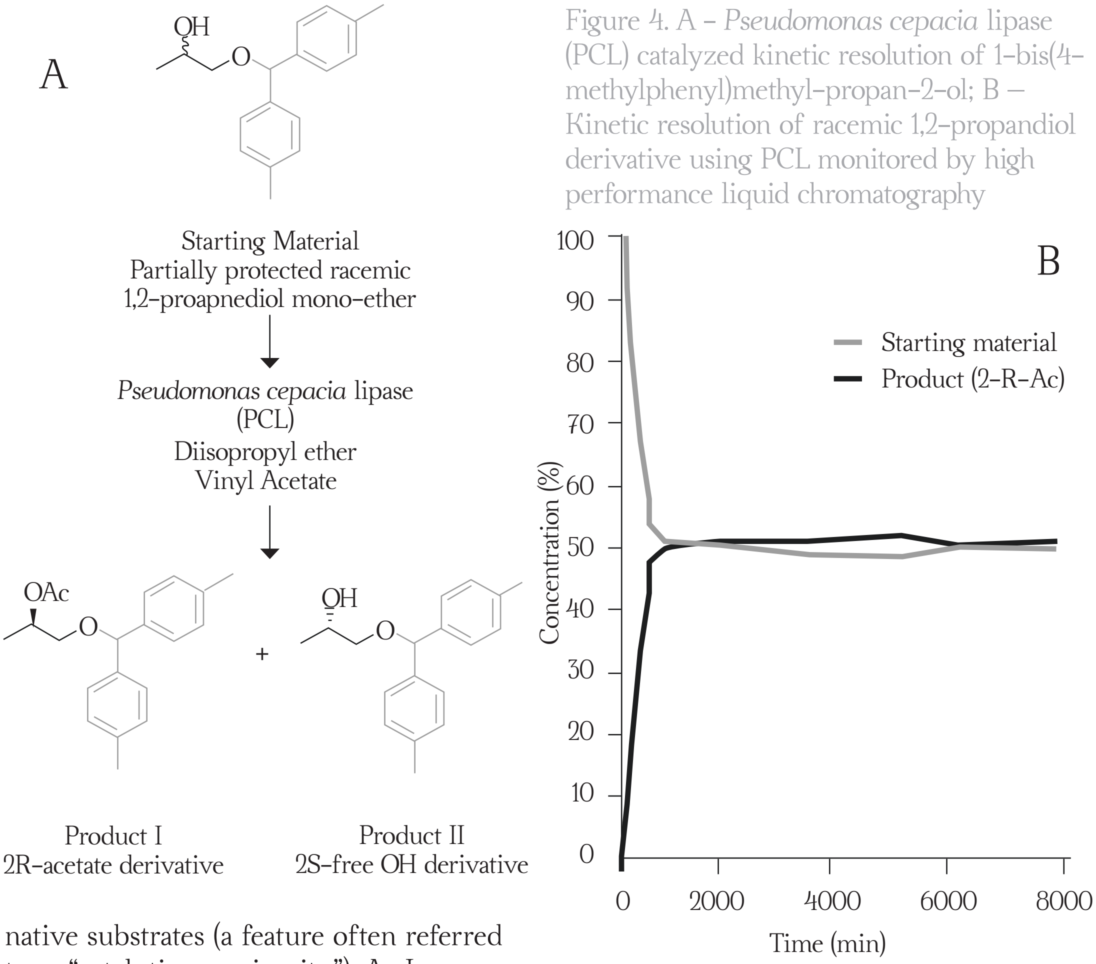


Figure 4. A - *Pseudomonas cepacia* lipase (PCL) catalyzed kinetic resolution of 1-bis(4-methylphenyl)methyl-propan-2-ol; B – Kinetic resolution of racemic 1,2-propandiol derivative using PCL monitored by high performance liquid chromatography

native substrates (a feature often referred to as “catalytic promiscuity”). As I neared graduation, I decided to use the opportunity to combine my love of organic chemistry with my new found appreciation for microbiology. The work I did for my B.Sc. thesis examined the use of lipases from psychrophilic or psychrotolerant microbes, such as *Pseudomonas cepacia (PCL)*, to resolve partially protected 1,2-propanediol derivatives. The approach I chose was two pronged: a regioselective protection using a variety of tin(II) halide catalyzed etherification reactions that had shown to have a high degree of regiopreference in partially protected carbohydrate diol systems followed by an enzymatic resolution of the two enantiomers (Fig. 4).

Given my extensive background with high performance liquid chromatography (HPLC), I decided to monitor the reactions in near-real time to ensure that only one of the enantiomers was indeed reacting. While the PCL-catalyzed reaction portion worked very well, there were issues with the regioselectivity of the initial protection step necessitating an extra derivatization step. While the project as a whole was only partially successful, it gave me crucial insights into the challenges of separating biologically relevant enantiomers and gave me the impetus to pursue other lines of thought to reach my goal of separating a racemic mixture.

BIOPROSPECTING FOR EXTREME ENZYMES AND CHIRAL PRODUCTS

Since finishing my Master's degree (albeit in a project focusing on carbohydrate chemistry), I have had the good fortune to manage a number of projects all of which have given undergraduates research opportunities at the intersection of microbiology and chemistry. The focus of this work has been on two fields: prospecting for enzymes with biotechnological potential and bacteria producing (*R*)- or (S)-1,2-propanediol. The logic behind these two approaches is that it is easier to produce an enantiomerically pure compound such as 1,2-PD rather than trying to separate a mixture of the two enantiomers after the fact and that producing these compounds from enzymatically treated abundant biomass (such as lignocellulose) would be the most sustainable approach.

The early work involved leading a few groups of willing undergraduate into the field to collect samples from Iceland's various geothermal areas (Fig. 5). Once in the lab, the laborious process of enriching samples and isolating pure cultures began and continues to this day (some 3 years later). One of the reasons for going after thermophiles was that it has not been widely reported that they are capable of producing 1,2-PD.

Screening for 1,2-propanediol producing bacteria and enzymes of biotechnological potential has since expanded to new environs fueled by the initiative of a new generation of undergraduate researchers. Watching students enrich and screen isolates from environments and finding new and exciting bugs and expanding the knowledge base has been rewarding in its own right.

Figure 5. Professor Johann Orlygsson (University of Akureyri) demonstrating sampling technique in geothermally heated stream while several undergraduate researchers look on.

PARTING WORDS

Science is very much an active endeavor, and one's ability to succeed can be very much enriched by making connections by different disciplines and moving out of your comfort zone. Once piece of advice I like to give my students is to fervently seek out new opportunities in science, whether at home or abroad, and to strive to create a culture of learning. There are many ways of enriching your undergraduate experiences beyond research including doing science outreach (a great activity for sharpening those communication skills while giving back to the community) as well as teaching, whether it be acting as a teaching assistant for undergraduate course work or tutoring high school students.

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FURTHER READING

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