Laboratory Exercise

A Survey on Faculty Perspectives on the Transition to a Biochemistry Course-based Undergraduate Research Experience Laboratory

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Abstract

It will always remain a goal of an undergraduate biochemistry laboratory course to engage students hands-on in a wide range of biochemistry laboratory experiences. In 2006, our research group initiated a project for *in silico* prediction of enzyme function based only on the 3D coordinates of the more than 3800 proteins "of unknown function" in the Protein Data Bank, many of which resulted from the Protein Structure Initiative. Students have used the ProMOL plugin to the PyMOL molecular graphics environment along with BLAST, Pfam, and Dali to predict protein functions. As young scientists, these undergraduate research students wanted to see if their predictions were correct and so they developed an approach for *in vitro* testing of predicted enzyme function that included literature exploration, selection of a suitable assay and the search for commercially available substrates. Over the past two years, a team of faculty members from seven different campuses (California Polytechnic San Luis Obispo, Hope College, Oral Roberts University, Rochester Institute of Technology, St. Mary's University, Ursinus College, and Purdue University) have transferred this approach to the undergraduate biochemistry teaching laboratory as a Course-based Undergraduate Research Experience. A series of ten course modules and eight instructional videos have been created (www.promol.org/home/basil-modules-1) and the group is now expanding these resources, creating assessments and evaluating how this approach helps student to grow as scientists. The focus of this manuscript will be the logistical implications of this transition on campuses that have different cultures, expectations, schedules, and student populations.

Keywords: *Computational biology; curriculum development; enzymes and catalysis; genomics proteomics bioinformatics; integration of research into undergraduate teaching; laboratory exercises*

Introduction

Twenty years ago, students at our institution who took laboratory courses learned techniques and procedures, but only through direct faculty-mentored independent research did they become involved in open-ended, hypothesis-driven research that had the potential for publication. In short, most only learned to be qualified technicians as undergraduates. After graduation, many of them entered Ph.D. programs where they learned to become scientists, developing and testing hypotheses, collecting and interpreting meaningful data for the peer-reviewed literature. This is frequently the situation in many undergraduate programs, where the excitement of discovery and risks of failure of hypothesis-driven science are available only to a select group of undergraduates. The purpose of our project is to increase engagement of undergraduates in science by bringing a sense of "real" research, where the answer is not known, to a teaching laboratory situation. Institutions that lack sufficient research space or simply have too few faculty members to provide independent research projects for all interested students could use this approach to

Volume 00, Number 00, Month/Month 2017, Pages 00–00
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Received 15 December 2016; Revised 31 January 2017; Accepted 26 March 2017
DOI 10.1002/bmb.21060
Published online 00 Month 2017 in Wiley Online Library (wileyonlinelibrary.com)

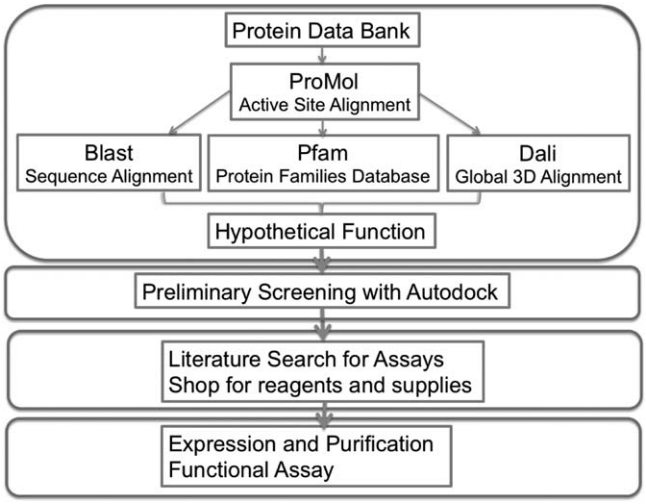

FIG 1 *Flowchart for characterization of proteins of unknown function.*

provide all of their majors with a genuine research experience. This increases the chances that more students capable of the journey will be launched towards scientific research careers, rather than turning aside. In addition, those who go on to careers related to their scientific coursework but not in full-time research will then do so with a much better understanding of the fields they are supporting and of the scientists and the science at the core of those fields.

Authors have been advocating for high levels of inquiry in undergraduate biochemistry laboratories for many years. A recent search of the literature revealed 19 different articles about noncookbook teaching laboratories containing elements of research dating back to a 1975 article by Paul Melius entitled, "A creative, research approach to the undergraduate biochemistry laboratory" [1]. Many of the article titles included the words "integrated" "project-based" or "project-oriented" [2–4]. In addition, many of these courses were designed around a single enzyme or protein [5–7] The incorporation of research in the teaching setting has been widely advocated [8, 9]. More recently, the acronym CURE (Course-based Undergraduate Research Experience) has been used to describe this approach and it has been advocated by many in the life sciences community. In a recent editorial, Bell *et al.,* [10] explained the motivation for using CUREs, reviewed the current state of CUREs in biochemistry and molecular biology courses, and provided examples of CUREs that have been offered at two-year and four-year colleges. They highlighted two large-scale CUREs that are based on nucleic acid work: SEA-PHAGES [11] and the Genomics Education Partnership [12–14] but pointed out that there are no such multicampus efforts in protein biochemistry.

It will always remain a goal of an undergraduate biochemistry laboratory course to engage students hands-on in a wide range of biochemistry laboratory experiences. In 2006, our research group initiated a project for *in silico* prediction of enzyme function based only on the 3D coordinates of the more than 3800 proteins "of unknown function" in the Protein Data Bank (PDB) [15, 16], many of which resulted from the Protein Structure Initiative [17]. Students have used the ProMOL plugin [18] to the PyMOL molecular graphics environment [19] along with BLAST [20], Pfam [21], and Dali [22] to predict protein functions. As young scientists, these undergraduate research students wanted to see if their predictions were correct and so they developed an approach for *in vitro* testing of predicted enzyme function that included literature exploration, selection of a suitable assay and the search for commercially available substrates (Fig. 1).

This approach has been very fruitful in our laboratories as we watch the transformation of our undergraduate research students. They begin by following our instructions, progress to exploring the questions in our grant proposals and then go one step further - they start asking their own questions, ultimately changing the direction of the project. One of our graduates recently entered a Ph.D. program in Biological Chemistry and was told that he is already performing at the level of a second or third year graduate student during his first research rotation. We decided to adapt our approach with individual undergraduate research students into a course-based undergraduate research experience where students explore these "proteins of unknown function." The course we have designed combines traditional laboratory techniques with computational and bioinformatics approaches to enzyme structure and function.

Recruitment of Faculty Participants

Initially, participating faculty members were recruited by the author based on existing relationships. Subsequently, several other members joined the team after reviewing a poster about the project at the 2014 ASBMB meeting [23]. Current faculty participants are listed in Table I. Early in our discussions, we decided to communicate via a blog (http://basiliuse.blogspot.com) and arrived at an acronym for the project: BASIL – Biochemistry Authentic Scientific Inquiry laboratory.

Focus of This Manuscript

The logistical challenges associated with implementing a new CURE on multiple campuses are described below. These include development of instructional modules that can be adapted on multiple campuses, software installation, software training, communication among team members, campus schedules, data sharing, and workload impact. Future manuscripts are planned that will address formal assessment of student learning in this course format as well as faculty development as the project unfolds and evolves. Additional manuscripts will feature a full description of the course modules with assessment tools, particularly for unique aspects related to computational modules.

TABLE I ***Participating faculty members and institutions***

Institution	*Faculty Members*
Cal Poly San Luis Obispo	Anya Goodman, Ashley Ringer McDonald
Hope College	Mike Pikaart
Oral Roberts University	Bob Stewart
Purdue University	Trevor Anderson, Stefan Irby
Rochester Institute of Technology	Herbert Bernstein, Paul Craig, Jeff Mills, Suzanne O'Handley
St. Mary's University	Colette Daubner
SUNY Oswego	Julia Koeppe
Ursinus College	Rebecca Roberts

Materials and Methods

Candidate Proteins

Since all of the proteins for the project have been crystallized with structures deposited in the PDB [16], plasmids containing the genes for each of these proteins were readily available, primarily from the DNASU plasmid repository [24]. The plasmids all contain His_6 tags to facilitate protein purification. Proteins were selected from the list of probable serine hydrolases that had been identified by the research group at the Rochester Institute of Technology as described in McKay *et al.*, 2015 [25].

Module Development

The team members began to create the course modules during the summer of 2015. Over the course of the following year, we adapted our existing protocols from our individual campuses, for example, a Bradford protein concentration assay [26], to work with the proteins for this project. By the end of the first year, the team members had jointly developed the modules based on their expertise. A time course for the project and the list of course modules can be found in Tables II and III.

Different Implementations on Different Campuses

Some campuses used all of the modules. One campus used only the *in silico* modules for a computational chemistry course. One campus implemented the *in silico* modules in a computational chemistry course and the *in vitro* modules in a biochemistry laboratory. The students then met and gave joint poster presentations.

Role of the PI and Role of the External Evaluator

Evaluation and assessment are central themes in our project. The PI is focused on evaluating challenges to implementation and the experiences and growth of the faculty

TABLE II ***Time course for the initiation of BASIL***

Dates	*Activities*
2006-2014	Undergraduate study of proteins of unknown function at the Rochester Institute of Technology
Early 2014	Recruitment of team members and submission of an NSF IUSE proposal
April, 2014	Recruitment of more team members via an ASBMB poster
October, 2014	Submission of a revised NSF IUSE proposal with all team members
July, 2015	Initial online team meetings and module preparation
Fall, 2015	Implementation on the Rochester Institute of Technology campus accompanied by excitement and panic
Spring, 2016	Implementation on other campuses with more excitement and panic
May-June, 2016	Interviews with all participating faculty members

TABLE III *Modules for the BASIL protein-based CURE*

Module	*Description*	*Outcome*
Protein expression	Plasmids are transferred to expression cell lines, which are then grown, induced with IPTG or arabinose, sonicated, and centrifuged.	Crude mixture that contains the active protein from the plasmid.
Protein purification	The protein is purified by metal ion affinity chromatography, followed by desalting on a gel filtration column.	Purified protein ready to be characterized.
Protein concentration	Protein concentrations are measured using the Bradford assay.	Sample volumes to use for SDS-PAGE and activity assays.
SDS-PAGE	Protein purity and molecular weight are measured by SDS-PAGE.	Confirmation of predicted protein size and purity.
Enzyme activity assays	Students look for product formation with a series of potential substrates.	Enzyme activity (and lots of excitement)
ProMOL/PyMOL	Protein structures are compared to a library of enzyme active sites to look for high quality alignments, indicative of likely activity.	Probable Enzyme Commission classes for the proteins of unknown function, along with lists of ligands or substrates for those EC classes.
BLAST	Analysis of protein sequences can provide further clues on function.	Function predictions based on sequence only.
Dali	Full backbone alignments of unknown proteins with sequence homologs may reveal structural features.	Full structural comparisons with interesting candidates.
Pfam	Students use protein sequence analysis to identify superfamilies and likely forms of activity.	Additional functional information.
Docking	Students use PyRX and Autodock Vina to identify potential ligands.	Binding affinity values can be used to discriminate among potential substrates.

A series of 10 modules were created for the CURE and they can be found at the promol.org web site (http://www.promol.org/home/basil-modules-1) and the BASIL blog (http://basiliuse.blogspot.com/).

members. The other instructional team members are teaching the laboratory course, refining the laboratory and developing gradable assessments for those interested in adopting this approach, adapting it to their campus or as a launching point for another protein-based CURE. The external evaluators from Purdue University are focused on questions of deeper learning by the students with a particular focus on our main research question: "Does this approach train our students to become scientists?"

Survey Methodology

The author prepared a survey of questions that focused on logistics and the BASIL materials and resources, with assistance from team members at Purdue (see Table I). The surveys were administered online and recorded using BlueJeans videoconferencing software (https://bluejeans.com/) and recorded. A transcript of the interview was shared with the subject for feedback and clarification. The answers to the questions were then pooled. A summary statement was generated based on the pooled answers and quotes are included in the manuscript as appropriate. The protocol was reviewed by the Institutional Review Board at the Rochester Institute of Technology (FWA # 0000731) and was issued an exemption under CFR 45 46.101(b)(1).

Results

Several well-known biochemistry laboratory manuals have been published [27–30] but I do not recall meeting any

TABLE IV *Survey of faculty participants*

Question	*Summary Statement*	*Quotes*
The first 8 questions focus on logistical aspects of the project.		
1. Logistical aspects for this project including finance, resource availability, purchasing, installation of software, use of time, people power. Would you change any logistical aspects including how the laboratories are presented to the students? If so, what and how?	The protocols should be firmly established before teaching the laboratory on any campus in a multicampus project. It would be better to have a uniform computer interface for all of the software for the project.	"Change the language so that we are not telling the student it's an experiment because the students tended to gripe about it when things did not work. "Would it work better to have a common project at the start and then have independent projects at the end?"
2. What modifications would you make to the laboratories, if any?	Start at least some of the experiments (enzyme activity, structural alignment) with a known case so students will have a clear understanding of a positive result.	"It might be nice to take one week and show the students a well-designed canned assay that works and is similar to what we want them to do."
3. Is the laboratory cost effective and feasible from a human and facilities resources point of view?	The major expense was the purchase of substrates, but the costs were within the normal range for a biochemistry teaching laboratory. The laboratory took more time than expected, especially prep time, which was about twice the normal amount.	"...it cost me about 10 more hours of work per week." "The part with the substrate ordering does not seem feasible." "The community of collaborators found some solutions. It is feasible to some extent, but the students may be limited in their choices of substrates."
4. Do you feel that you're being well supported by other group and subgroup members or are you being left to work on your own? If necessary, how do you suggest things could be improved?	Camaraderie and cooperation grew quickly within the group of nine faculty members on six different campuses. The sharing of protocols was very helpful. People who ran only the computational modules sometimes felt isolated.	"Yes, I was very much supported by the BASIL group. I would not have gotten past day one for computational stuff without the help of the group." "I was unsure how someone without more computational training could trouble shoot all of these problems. We may need to have people paired up (biochemistry and computational)."
5. Do you have the necessary human, financial and facility resources? What is the incremental increase in expense compared to your normal expense for teaching the laboratory? How much additional time did this take you?	Most participants felt that the expenses were comparable to the laboratory curriculum they had been using. It took more time than the previous curriculum to prep for the course. Several campuses need an upgrade in instrumentation.	"I did not get good support from my institutional IT guys and did almost all software installation myself." "It was vastly more time consuming. I almost pulled an all-nighter to get ready for the next day one time."
6. Are you being well supported at your institution or are there any barriers to implementing the course? Please be specific about barriers at different levels: *A. Personal Level*.	A few faculty members needed to learn wet laboratory techniques and many experienced a steep learning curve for the computational part of the project. Some experienced self-doubt.	"Seemed like we were always working against the clock." "I need to be ready well ahead of the lab; I was not comfortable with not knowing the answers when I walked in the lab. At the same time, it was unexpected and fun - when students started to get results, the pace

TABLE IV *(Continued)*

Question	*Summary Statement*	*Quotes*
The first 8 questions focus on logistical aspects of the project.		
		really picked up and I felt like a post-doc for a week or two. The excitement and engagement was really exciting - to have students stopping by my office with new results."
6B. Resistance by Colleagues	Colleagues were very supportive. On two campuses multiple colleagues from other departments attended a poster session that was offered on campus at the end of the term.	"I am now the most senior biochemist, so I am in a good place to try something new. This might be tough for a new assistant professor trying to change things in a culture."
6C. Resistance at the Departmental or Institutional Level	On several campuses, the computer support departments were not supportive. Some departments don't view pedagogical research as scholarship. Also, some had difficulties with curriculum committees at various levels.	"My Dean is not a barrier, but he is not supportive. He was not aware that he had signed off on my NSF IUSE proposal." "Lots of positive press. At the return to school meeting in the fall, the NSF project was highlighted."
6D. Resistance at the National Society Level	The national organizations (American Society for Biochemistry & Molecular Biology (ASBMB), American Chemical Society (ACS), Biophysical Society) were very supportive of CURE-type laboratories.	"ACS is my society and they are extremely supportive of CURE. I am also in the ACS Committee on Professional Training. They have identified capstone experiences as one of their seven best practices. They have also acknowledged that a 1:1 faculty to student ratio is unrealistic, so they support CURE."
7. What is the status of teaching assistant and technician training at your institution? Will they all be competent to support you in implementing the laboratories? How should we network the teaching assistants and technicians across the project? Should it be formal or informal?	None of the campuses had formal teaching assistant training, although most campuses did have teaching assistants for the course. None of the campuses depended on stock room support for reagent preparation. In most cases the teaching assistants were helpful. We did not try to get them to network with each other.	"The teaching assistant was competent. Should we network the teaching assistants across the project? That could be very useful, as another way for them to learn things." "It would have been helpful for any teaching assistant on any campus to have our teaching assistant as a resource to fall back on. The teaching assistants from Rochester Institute of Technology are highly experienced and have spent time on the project. Informal [networking] would be great."
8. Do you envisage sharing your knowledge with other colleagues and institutions so that they could also introduce a similar laboratory course? If so, with whom and how	All of the participants are eager to share their experience and seek to identify collaborators despite the increased workload from the	"I hope that this research approach will become the norm." "I shared it at EnFUSE (AAAS/NSF 2016 conference, **En**visioning the **F**uture of **S**TEM **E**ducation). Trying to engage

TABLE IV *(Continued)*

Question	*Summary Statement*	*Quotes*
The first 8 questions focus on logistical aspects of the project.		
would you do this? How would you aid them in implementing the laboratories?	project. Five have already presented at national meetings.	our college communications office to do a story about it. I will talk to folks I know, go to meetings and try to get some publications out. The issue is to highlight the idea that we are building scientists who are doing true science. There is a learning curve to implement this. We have to show the deep worth of it to newcomers."
Questions 9 and 10 are about management of grant funds.		
9. Do you have any feedback about this? Are you happy with your grant and will it be adequate to achieve your goals?	The funds for supplies were helpful but not essential. A bit more summer salary would have been nice. All team members stated (without being prompted) that funding for a face-to-face meeting as a group would have been very helpful.	"I would have liked to have funds for all of us to get together for 2-3 solid days."
10. What is the sustainability of these proposed laboratories in the longer term?	In general, the expenses are comparable to normal costs. The three major hurdles will be (1) identifying additional classes of proteins to study, (2) buying or preparing the substrates for the predicted functions, and (3) the central role that each faculty member plays on her/his respective campus.	"If we move from hydrolases, that will be a barrier." "Could we make the class more streamlined through instructional videos?" "There is a personnel sustainability problem. If [the BASIL team member] disappeared, the class would disappear."
Questions 11 – 13 focused on faculty development.		
11. In your view, does this laboratory sequence do a good job of training upper level students to become scientists?	We noted progress on all campuses, with some real excitement from students who presented their work on campus or at conferences. We believe this approach is having an impact, but it will need to be assessed rigorously. Some of the experiments were fairly routine (protein expression and purification), but some really did have a sense of discovery (enzyme activity, bioinformatics).	"Yes, but we need to do assessment on it. The question models the way people will do science in real life, but we are doing this in the classroom with time constraints and other constraints (equipment, reagents). How can we mitigate the constraints or take advantage of them? For example, in a research lab, there is usually a more senior person (grad student, post-doc). In the lab, everyone can be a leader, but the faculty has to manage it well - withhold information sometimes, to let students figure it out and get a sense of pride/confidence that they can do it."

TABLE IV *(Continued)*

Question	*Summary Statement*	*Quotes*
Questions 11 - 13 focused on faculty development.		
12. Have you improved your pedagogical knowledge? Please give an example. How did you change? Would you like to learn more in this area?	About half of the participants felt they had improved in their pedagogical knowledge, but even those participants wanted to be involved in a more formal assessment to figure out where they stood. One of the challenges was to make the students do the discovery instead of steering it or suggesting a likely answer to them.	"Yes. The pedagogy for what works well for implementing CURE in the classroom, there are some successes, but it is challenging to scaling in a lab with 16 research students and one instructor. We are figuring this out as we go along." "I had to try to not tell the students everything and encourage them to teach each other."
13. Were the online workshops for faculty and IT specialists for protein software training and installation useful? Would you change anything? If so what and how?	The group meetings had a positive impact on the implementation of the courses, but there were drawbacks. Software installation was a significant challenge on half of the campuses. The video tutorials were very helpful, but did not address all concerns.	"Weekly conversations helped 75% of the time. Being able to ask questions and get answers. Hearing how others approached things. Camaraderie - people who care about the same things I care about. Sharing the excitement. 25% did not work - specific issue on one particular campus that went on and on."
Questions 14 and 15 focused on the process of protocol development and implementation.		
14. Are you happy with the process being used of protocol development?	Most participants were not happy because we did not complete the protocols before we started the 2015-2016 academic year. During that first year, many of them simply adapted protocols from their previous experience for the wet laboratories (protein expression, purification, concentration, SDS-PAGE). The real challenge occurred with trying to implement the bioinformatics modules without sufficient preparation.	"I expected to have full protocols before we taught it in the spring. We need assignments, learning objectives, rubrics, protocols, background theory on everything, how to present it to the lab. We were missing an explanation of how to interpret the data." "I did not use the protocols that anyone else wrote. I needed to write all of my own protocols. There are multiple problems here - minor differences in implementation on different campuses, so the words are different. I also had other learning objectives to meet for my class that others did not have, so my protocols were different." "We need to uniform protocols, especially if this will be exported." "It could be more efficient or streamlined but I don't know how. What if we were all sitting in the same room for a week and just hammered it out then. I am sure that the virtual meetings are beneficial, maybe just not optimal. While the virtual meetings seem to be working, we may have had better/faster results with in-person meetings."

TABLE IV *(Continued)*

Question	*Summary Statement*	*Quotes*
Questions 14 and 15 focused on the process of protocol development and implementation.		
15. Are you happy with our adjustment from having a one-week summer intensive workshop to a weekly practice/demonstration/discussion through the summer?	The modules were sufficiently new for most of the team members that a one-week intensive online workshop would have been overwhelming. However, a one-week workshop on a single campus would have been well received.	"I would rather have met all in one place for one week. This would be educational and team building. This should be in future grants. It would have been huge."
Questions 16 - 18 relate to specific protocols, especially for the computational laboratorie**s.**		
16. How are you planning to implement the laboratory? How will you monitor the progress of implementation?	Several people suggested running the computational laboratories first with an enzyme of known function so the students can see the kind of results to expect and understand a bit about how to interpret them. Students were monitored by observation and by laboratory reports, but the approach varied by instructor. On some campuses students made presentations during the laboratory period to each other. On two campuses, the students gave public poster presentations at the end of the laboratory.	"Reflecting on last fall, the students came in on day one and they received a list of seven to ten hypothetical enzymes and we asked them to pick one. I then ran them through each server and helped them understand the results. Next spring, I will have them start with an enzyme with a known function to see the kind of information they will get from the servers. Then I'll let them choose their targets and have them repeat the exercise with their unknowns."
17. Do you have any feedback on the protocols developed so far? Are you happy with them? How would you change anything? Are you uneasy about anything?	The protocols are good resources that none of us could have developed as individuals. At the same time, they need to include more background, clear learning objectives and assessment strategies. Video resources were very helpful, especially for the *in silico* laboratories. Some of us were more comfortable than others in this process.	"Yes. It took some work, especially on the computational side. I had to jump in head first with the class. It is important for an instructor to model this for the students. I hope not to teach this as a check list, but to approach it from a discovery perspective." "No, not necessarily. Some seemed to be written in a foreign language. One document was intimidating."
18. Are you running some of the modules but not all?	On four campuses, the instructor attempted to run all of the protocols; in one case, they did not get to the docking studies. On two campuses, the modules were divided - the wet laboratory parts of the process were done in the biochemistry teaching laboratory and the computational modules were covered in a computational chemistry course.	

Each question was presented to each interview participant. Summary statements were crafted from their responses and quotes were included where appropriate.

biochemists who teach their entire undergraduate biochemistry laboratory course from one of these texts. One or two experiments may be adopted, but we frequently develop our courses around projects that may connect to our research interests [2–7]. The members of the team had all developed unique biochemistry teaching laboratory courses on their campuses and had all experimented to some extent with inquiry-based learning. The results of the survey of the nine faculty members who implemented the BASIL modules (Table IV) on their campuses communicate the shared challenges in the transition to a CURE-type laboratory course. Each of the questions is listed, along with a summary statement of the responses, with direct quotes where appropriate.

Discussion and Conclusions

There are many challenges in properly implementing a CURE approach to a regularly scheduled biochemistry laboratory course for undergraduates: development of materials and resources, preparation time for each the course each week, learning unfamiliar techniques, and dealing with change on multiple levels (personal, departmental, institutional). The team that took on this challenge encountered significant frustration, primarily resulting from the fact that we did not have the modules fully ready to run when we began teaching the laboratory sections. This was the result, in part, of the fact that the implementation is different on each campus, because of different time zones, levels of expertise, the term schedule, class size, or available instrumentation. Other challenges included the steep learning curve of some of the bioinformatics software, along with the challenge of installing the software on different operating systems behind firewalls that were unique to each campus.

Despite these frustrations, none of the team members left the project. If team members lacked the necessary skills for either the *in silico* or *in vitro* aspects of the project, they would reach out to others to gain the insight they needed to effectively teach the laboratory for which they felt least qualified. In fact, everyone is enthusiastic about presenting the BASIL modules at their favorite national conferences and sharing this approach with their colleagues. Over the course of the project, the team held weekly videoconferences to resolve issues that arose on each campus and to continue to refine the modules for future use.

Some of the issues that were raised during the interviews have been resolved. There is now a full set of BASIL student modules available at the promol.org web site (http://www.promol.org/home/basil-modules-1) and the BASIL blog (http://basiliuse.blogspot.com/). These sites also contain links to videos for training on use of the software tools for the project. A uniform user interface is available with a virtual machine, BASIL 1.0, which is publicly available on the Cyverse/Atmosphere web site (https://atmo.cyverse.org/application/images/1387). This is freely accessible to registered academic users. BASIL 1.0 contains the open source software for the project in a Linux Ubuntu graphical user interface that closely resembles the Windows or Mac environment. Our future plans include creating instructor modules that contain expanded or alternate exercises, systematic learning objectives and suggested assessments. One pending manuscript will focus on the modules that have been developed and the associated tutorials and other web resources for the project. Other future manuscripts from the project will address the taxonomy of establishing and sharing a CURE, as well as a deep assessment of student learning, in which we plan to address our primary goal, which is to train our undergraduate students to develop as scientists in their biochemistry laboratory courses.

Acknowledgments

Many thanks to my coworkers for their efforts on the BASIL project and their participation on the survey: Trevor Anderson, Purdue University; Herbert J. Bernstein, Rochester Institute of Technology; Colette Daubner, St. Mary's University; Anya Goodman, Cal Poly San Luis Obispo; Stefan Irby, Purdue University; Julia Koeppe, SUNY-Oswego; Jeff Mills, Rochester Institute of Technology; Mike Pikaart, Hope College; Ashley Ringer McDonald, Cal Poly San Luis Obispo; Suzanne O'Handley, Rochester Institute of Technology; Rebecca Roberts, Ursinus College; and Robert Stewart, Oral Roberts University. We are particularly grateful to Frances C. Bernstein for her editorial insights on the manuscript.

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