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Advice for New Faculty: Structuring a Summer REU Project and Mentoring the Participant to a Publication

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Abstract – Due to strategic funding initiatives by the National Science Foundation, Research Experiences for Undergraduates (REU) programs have become widely regarding as a beneficial experience for students considering graduate school. Institutions that successfully secure REU site grants have dedicated faculty interested in promoting undergraduate research. This is important because the time involved mentoring undergraduate REU participants for an intensive 10-12 weeks during the summer is significantly greater than the time spent mentoring an established graduate student. The rewards for the faculty mentor can include energizing an undergraduate participant so that they pursue a graduate degree under the mentor's direction, advancing a research project, and publishing a paper with the undergraduate on the summer research project. For a new faculty member, these benefits are crucial for P&T documentation.

This paper strives to provide guidance on how to structure a summer REU participant project so that the student has an extremely positive research experience, quality data is obtained, and the project reaches a completion point in 10 short weeks. For example, an ideal REU project would have a solid foundation from the mentor's ongoing research efforts that is within the expertise of any graduate student mentors and for which a preliminary literature survey has been conducted. Per NSFs requirements, the project needs to contain an independent problem solving component and this necessitates that the student have clear, attainable objectives with immediate access to necessary research tools. The scope should be sufficiently narrow such that controls and dependencies are apparent and thus yield meaningful outcomes. Many factors influence progression of a short research project into a publication ready manuscript. However, a well-defined project and strategic mentoring of an inexperienced, yet dedicated undergraduate researcher can yield quality results and a working draft of a viable manuscript in 10 weeks. This paper will outline tips to accomplish this goal.

Keywords: Research Experience for Undergraduates, Research Program, Professional Development, Projects.

INTRODUCTION & BACKGROUND

The National Science Foundation (NSF) has an ongoing effort known as a Research Experiences for Undergraduates (REU) program [1]. The goal of this program is to support active research participation by undergraduate students with the long-term goal of encouraging more students to pursue advanced degrees and to increase participation of groups traditionally underrepresented in science and engineering. One key attribute of such a program is that the REU projects must involve students in meaningful ways – i.e. the undergraduates may not be simply lab technicians. It is viewed favorably if the REU Sites include professional development training including ethics. Also, involving participants from diverse schools across the country (especially those from primarily undergraduate institutions) as well as inclusion of an international component is also viewed as favorable because it broadens REU Participant perspectives and increases the breadth of their training. The research theme of REU Sites is open to any research area that NSF currently funds. Of course, themed sites with an interdisciplinary or multi-department research component are good [2,3].

This paper strives to provide guidance on how to structure a summer REU participant project so that the student has an extremely positive research experience, quality data is obtained, and the project reaches a completion point in 10 short weeks. The programmatic activities mentioned here are examples derived from the author's REU program, "Chemistry / Chemical Engineering: The Bonds Between Us" [3]. Assessment figures for this program can be found in the paper, "Outcomes of a Novel REU Site in Chemistry & Chemical Engineering," by Adrienne Minerick in the 2008 ASEE Proceedings [5]. Other REU programs will usually have similar activities and the advice included here can be tailored to those programs. Further, the advice included here can be tailored to structure a supplemental REU experience on any NSF grant [see reference 1 for more information].

Purpose and Goal of REU Programs

REU site programs may run during the school year, but the most common form is a summer internship. A ten-week summer experience that enables an undergraduate student to emerge himself or herself in research can be a life-changing experience. For the students, it really is a no-risk chance to see if they love research. The students are paid a stipend along with other support which may include housing, food, trips, and miscellaneous. Students are typically paired with a faculty advisor and possibly a graduate student mentor. These mentors help guide the undergraduate student through their first independent research experience. Exit evaluations and discussions with participants often indicate that they are surprised when their projects do not work perfectly in line with the objectives they were assigned at the beginning of the summer (unlike the "cookbook" undergraduate lab classes they may have previously experienced). A previous REU participant summarized this feeling in his / her exit evaluation as, "It's called re-search - things fail, and you are supposed to try again. Otherwise it would just be called search." The purpose of REU programs is to provide a meaningful, hands-on experience that hopefully excites students into pursuing advanced degrees in their field.

Professional development and research skills training are typically interspersed with laboratory or simulations research. Extracurricular activities including site visits of industry or national research labs, social activities, interactive workshops on essential topics such as diversity and research ethics, and an end-summer research symposium. This presentation at the conclusion of the summer is a perfect motivator for students to pull their project to completion and then submit an abstract to present at regional or national professional society meetings, an activity that simultaneously provides productivity measures for the faculty member.

Programs are typically designed with variations of the following attributes in mind:

- State-of-the-art research experiences that motivate students to pursue graduate degrees in engineering.
    - Broad participation of underrepresented groups
    - Increased appreciation and understanding of research
- Sense of community among REU students, faculty, and graduate student mentors
- Enhanced educational and mentoring experience for graduate students

The faculty mentor plays a key role in the process. New faculty especially need to make sure that the effort they put into mentoring a student in this worthwhile program has a return on its investment. In other words, the participant's project should lead to at least a presentation or poster at a professional meeting, but more ideally, it should provide a substantial contribution to a paper prepared for peer-review.

Enabling Meaningful Research Experiences

The primary goal of a summer research experience is to offer an informative, positive immersion in research so that participants can make an informed decision as to whether they would like to pursue an advanced degree or pursue a career in research. Therefore, it is necessary to have well-defined projects that enable successively more independence as the participant's competency grows. It is important that the project enable true research and that the participant does not simply act as a lab technician for a graduate student's project. This section will discuss how to structure 10-week REU student projects to maximize productivity for the faculty member's research while simultaneously facilitating a transformative and positive experience for the undergraduate both in the laboratory and in crafting their own professional career credentials.

Structure Projects via Intermediate Objectives

An ideal REU project has a solid foundation from the mentor's ongoing research efforts that is within the expertise of any graduate student mentors. The project should have a preliminary literature survey conducted and organized for the student such that the student can build upon this body of literature. Per NSFs requirements, the project needs to contain an independent problem solving component and this necessitates that the student have clear, attainable objectives with immediate access to necessary research tools. The scope should be sufficiently narrow such that controls and dependencies are apparent and thus yield meaningful outcomes.

Providing the student a project description along with descriptive objectives and estimates of the timeline for each objective is particularly useful. At the beginning of the summer, students think they have all the time in the world to complete the project, but by about week 6, they are frantically trying to finish up experiments. By providing smaller objectives and shorter milestones, inexperienced students do much better at managing their time. Structure training as an "apprentice progressing to a journeyman", by providing intermediate objectives that include becoming proficient on a piece of equipment or reproducibly preparing a sample with certain properties.

For example, one project might involve functionalizing a surface with a special polymer. The lab skills to accomplish this task independently must be developed and, depending on the complexity of the procedure, it may take a couple of weeks for the student to consistently and reproducibly accomplish this task. Next, the student should be directly responsible for characterization of that surface with only one or two instrumental tools. Inexperienced research students have a steep learning curve to surmount when working with complicated instrumentation for the first time. For the student's background and to ensure the quality of data obtained, students need the time to learn and develop a fairly deep understanding of how a piece of equipment works, the principles behind the measurement technique and the limitations of the measurement as it relates to their sample. One technique that is particularly educational is to develop a detailed experimental plan for the participant on the first instrument, but then ask the student to develop his or her own experimental plan for the second instrument.

In a 10-week program, it is usually only possible for the student to complete 3 to 6 objectives, depending on objective complexity. The first week of the program is usually comprised of orientation and then understanding the project itself. Shadowing a graduate student or preliminary learning of the techniques employed in that laboratory can continue into the second week of the program. The final week of a summer program is usually consumed with final poster or presentation preparation and final report writing. This means that only 7 or 8 weeks are available for student research. Each objective can only require, on average, 1 to 2 weeks to complete.

Try to structure the objectives so that there is a coupled deliverable that the student perceives as needing to produce to show objective completion. The new faculty can use these products as a means to build together a viable manuscript (see the section on Developing a Viable Manuscript). The intermediate objectives can be tailored to include a deliverable by requiring a demonstration on a representative sample as evidence that the objective is complete. Production of a sample with given properties can be measured by having the student produce a picture of the sample or a plot of the properties as measured by a given tool. The faculty can then guide or tailor these products to be publication quality so that they will interface easily into the manuscript at the end of the summer.

Inexperienced students will not necessarily know how to compile individual data measurements into plots to show trends. It can be beneficial for the new faculty member to clearly outline exactly how traditional plots in that field are structured. Pull up a file with data from a similar experiment and show plots, etc., then asking the student to reproduce a similar plot with their data. Another option is referring back to the literature in the preliminary literature survey they were provided and having the student develop their own version of such plots. Later in the summer, it can be beneficial to ask the student if they can brainstorm additional ways of representing the data to show dependencies they observe.

Sometimes, objectives are closely coupled or overlap so that one doesn't necessarily need to be completed before the next begins. This is frequently true in laboratory type experiments. Inexperienced researchers will tend to try to complete all of the experiments first before beginning on data analysis. Experienced researchers know this is a poor strategy because any technique error will propagate through all of the experiments. Data analysis should be structured as ongoing so that the student doesn't errantly run numerous experiments incorrectly or fail to produce meaningful results. In this case, it may be beneficial to have as a deliverable a developing data table or frequently updated plot. The new faculty should assume that the student does not know how to conduct rigorous analysis and provide an example first, then ask the student to reproduce or build upon the analysis for their own project.

Revisit the objective milestones frequently during the summer with the student doing progressively more planning for completion of the later objectives. Given the golden rule of research, which is that things usually don't work or progress as planned, use this as an opportunity to encourage the student to learn to plan for contingencies and to thoroughly enjoy discoveries and successes during the experience.

Research Outputs

The key for any new faculty engaged in advising undergraduate researchers is ensuring that the effort invested in the student yields a product for the faculty members research program. Possible forms of output which add to a faculty members research program are data compiled into publication quality plots, development of new lab procedures, algorithms, programs, or simulations, posters or presentations, and a viable manuscript for publications. In many REU programs, data is the most common output and any presentations or reports required can be perceived to be for the student's benefit so they learn skills to aid them in future research endeavors. The data is sometimes absorbed by the supervising graduate student's research with secondary credit given to the REU participant. There is no reason why these presentations and reports can't be immediately interfaced into a viable research manuscript that gets submitted for publication and remains separate from the graduate students research.

Strategic inclusion of research outputs into a viable manuscript or completed project takes careful planning. When research is going smoothly, these smaller outputs build together into a cohesive puzzle. Programs usually include an oral presentation, but in our program, we discovered the merits of having the participants do a 10 to 12 minute oral presentation on their research project and preliminary data at approximately week 6. This enabled the students to pull all the foundation information together on their project, and organize it such that they could explain it to their peers and their mentors in a formal setting. The proficiency of the students in the lab increased after this milestone making its educational impact all the more valuable. Further, the students were able to build from this presentation to do their final posters and final papers. The quality of the final student posters was greater in the two most recent summers than in the first year of the REU program. To increase pride and student investment in their research product and to increase probability that the students would present at regional or national professional meetings, participants were provided mailing tubes for their posters so that they could take them home.

Presenting at Conferences

NSF strongly encourages programs to facilitate involvement of participants in regional or national student conferences. In our program, participants were provided their posters; they were encouraged to seek opportunities to present their projects at conferences when opportunities arose. Sometimes, national professional societies offer travel grants, For example, the American Chemical Society helped sponsor students to attend regional conferences to present their research via a fellowship program. Also, some schools co-sponsored American Institute of Chemical Engineers student officers to attend the national conference and the given REU program can thus supplement their expenses. ASEE regional conferences are also an excellent place to encourage participants to present because travel and expenses are much reduced. Online Celebration of Undergraduate Research sponsored by NSF's Division of Chemistry REU Leadership Group, partnering with the Colorado State University Libraries has featured student projects on their websites as well [http://reu.library.colostate.edu/]. REU budgets are extremely tight, so facilitating opportunities for students in this area is always a challenge. However, it is well worth the efforts because any venue where a new faculty member can have their research featured is a step in developing a national reputation and will thus impact tenure and promotion.

GUIDING DEVELOPMENT OF A VIABLE MANUSCRIPT

In addition to the research experience within the laboratory, the participants can also gain experience articulating research procedures and results into manuscripts, posters, or presentations. Many programs already facilitate oral presentations and posters. However, for new faculty the development of a viable manuscript is the single most beneficial output that can result from a summer research experience. Sometimes reports are required as part of the program, but the faculty member can always tailor these reports to be stepping-stones to full research papers. In the author's REU program, a formal course accompanied the REU and provided some structure to paper development.

Advanced Research Skills Course

As an unique and beneficial perk of MSU's REU program, participants enrolled in a three credit hour course, CH 4613 Advanced Research Skills, which they could transfer to back to their home institution [4]. Topics covered in this course included: Safety, Research and the laboratory, How to maintain a lab notebook; Literature searches and article applicability to your research; Dissection of a research article; Effective scientific presentations; Preparing an abstract of your research project, and Preparing a scientific poster. At approximately week 6 of the program, all participants were mentored through preparing a 10–12 minute oral PowerPoint presentation of their research. Two afternoons were dedicated to participant presentations for the entire Bonds community (faculty, graduate students, and peers). For the final week of the program, students prepared a 3X4 foot poster on their finished research project. This was presented during the Closing Poster Symposia and the entire Bonds research community and the greater MSU community was invited [4].

Drafting the Paper

To be able to successfully mentor a brand new researcher to complete a technical manuscript, it is necessary to break the task into small subtasks. Most manuscripts include an abstract, an introduction which includes the motivation for the research, background information and review of the literature on the subject followed by a clear articulation of the premise of the research project, a materials and methods section providing a description of the experiments and analysis, a results section including plots of data, and interpretations / conclusions. An undergraduate's role in crafting each of these suggestions is discussed below.

In the first week or two, after discussing the project with the faculty and graduate student mentor, and after reading the project description provided along with the summer's objectives, a student can begin by writing an abstract. It is beneficial to provide them the following questions, as a means to guide what should be included in the abstract.

1. What you will do / has been done,
2. Why is it important?
3. How will you do it?
4. What results were obtained and how will they be presented?
5. What is the meaning / impact of the result?

Iteratively revise this abstract with the student as a preliminary example of how the revision process for an entire manuscript occurs. This process can also help elucidate any areas of misunderstanding that the student has about project concepts, etc.

Next, the student can begin writing a 1-paragraph summary for each of the articles provided to them in the preliminary literature search. Depending on the length of the paper, three days are needed for the student to read the article and write a summary. This length of time will decrease as the student gets more experience reading articles and becomes more familiar with the research area. Also, as the student matures, they begin adding qualitative assessments on how the article relates to their own project. Some students will begin searching for additional articles from the literature under the guidance of their graduate student mentors. One of the benefits of MSU's Advanced Research Skills Course is that this activity is required as part of the course.

Once the student becomes proficient with their experiment in the lab, they can write a preliminary draft of an experimental procedure. Via iterative editing with the faculty or graduate student mentor, the REU student will learn to write this in a manner that provides enough information concisely that the experiment could be reproduced elsewhere. As the student's knowledge and skill set grows and the body of research results they have produced grows, they can move onto developing an outline for the results section. It can be useful to first discuss (via oral communication) the goals of a paper and the major sections. The student can then go independently produce an outline, which can then be refined via face-to-face written communication. At this stage, the advisor needs to resist the urge to take over outlining or writing the first draft of the paper to save time; the process of iterating with a student is important for their growth as a professional. In fact, it is advisable for a more experienced graduate student in the group to read abstract or paper drafts to provide experiential guidance and language / grammar edits. This first review can be less stressful for the new author, provide experience for the senior member, and save the advisor valuable time with low level edits.

In general, most new research students find writing their first paper to be intimidating and frequently do not know what to include and have the tendency to skip over any information they mastered quickly because they feel it is too simplistic. This tendency to complicate the task is a common one that is usually overcome by focusing on the individual sections. In order to write the results and discussion section, it can be useful to use the student's oral presentation of their results two-thirds of their way through the program. It can be useful to tape-record the student's discussion of the figures in this presentation and then have them type their words in as the first draft of the results and discussion section. This can serve as a good starting point for either iterative editing between the student and the faculty or for the student to sit with the faculty and edit the paper together. In the latter approach, more time is required, but it can provide substantial education for the REU student because they can see where and why edits are important.

The conclusions for the paper can be written from discussions of results near the end of the summer program. By this time, the student can have compiled the components of the paper together. It is necessary for the faculty member to complete the background and remaining literature review for the introduction. New research students immersed in a project for only a summer typically do not have the perspective to complete this section of the paper. Alternatively, the graduate student mentor can help by writing this section thus providing an additional educational experience for them. Final edits and revisions on the paper can be done via email once the program is over. However, the new faculty should target submission of the paper to be approximately 1 month after the completion of the summer program. This is partially for their benefit, but also because the REU student quickly get immersed back in their schoolwork in the fall semester and it is hard for them to find time to complete an involved paper.

Provide Experience for Graduate Student

An REU program is a beneficial experience for a graduate student on many levels. The graduate student gets first hand experience mentoring and teaching a less experienced protégé, an activity that substantially advances their own understanding of their research area and helps them mature professionally. In addition, giving the graduate student opportunities to edit the undergraduate's paper can improve their own writing and paper crafting techniques. As an aside, REU participation in the lab can reenergize graduate students in a lull and can reinvigorate them on the fun that is research.

A final approach to foster the mentoring experience of other graduate students in the REU program is to have them participate in the peer-review process. For example, at the end of the summer, have graduate students in the group not affiliated with the paper serve as reviewers. They can provide written reviews of the submission in the same manner as would occur for a professional journal. Such student-student interaction allows them to establish a formal professional relationship with their REU colleagues while advancing their own research skills.

SUMMARY & CONCLUSIONS

This paper discussed how a new faculty member can structure and organize a Research Experiences for Undergraduates experience to provide a positive experience for a new research student while simultaneously producing a viable manuscript which can be submitted for publication and greatly benefit the faculty mentor. The time involved mentoring inexperienced REU participants for an intensive 10-12 weeks during the summer is significantly greater than the time spent mentoring an established graduate student. Efforts to publish results are very consistent with REU goals to support active research participation by undergraduate students with the long-term impact of encouraging more students to pursue advanced degrees and to increase participation of groups traditionally underrepresented in science and engineering.

This paper strived to provide guidance on how to structure a summer REU participant project with a solid foundation from the mentor's ongoing research efforts within the expertise of a graduate student mentor, with an independent problem solving component with clear, attainable objectives, and with immediate access to necessary research tools. \ Many factors influence progression of a short research project into a publication ready manuscript. However, a well-defined project and strategic mentoring of an inexperienced, yet dedicated undergraduate researcher can yield quality results and a working draft of a viable manuscript in 10 weeks. Further, this contribution discussed the strategies that The Bonds program at MSU utilized to accomplish these goals and provided guidance on structuring student projects to maximize student learning and productivity. A ten-week summer experience can enable an undergraduate student to emerge him or herself in research and can be a life-changing experience. The rewards for the faculty mentor can include energizing an undergraduate participant so that they pursue a graduate degree under the mentor's direction, advancing a research project, and publishing a paper with the undergraduate on the summer research project. For a new faculty member, these benefits are crucial for P&T documentation.

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