An REU in Glass Science – Lessons and Legacy for Undergraduate Materials Education
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ABSTRACT
Two important goals of the International Materials Institute for New Functionality in Glass (IMI-NFG) have been: (a) to facilitate international collaboration in glass research and, (b) to support the training of a professional workforce [1]. The REU program has been an important component of its mission since 2005. Glass science provides the central theme of our program, which has both an international and domestic component. In this paper we provide a summary of our accomplishments and experiences with this innovative, materials focused, multidisciplinary REU program. While glass provides the unifying theme of our program, the research topics and project advisers come from various departments, including not only materials science and engineering, but also biology, physics, environmental and civil engineering, electrical engineering, etc. This mode of REU operation has provided an effective means to introduce faculty from other departments to new, interdisciplinary applications of glass as an enabling material for their own work.

For the domestic REU, we partner with the Physics REU Program at Lehigh, sharing many crucial administrative aspects including housing, seminars and social events. The complementary approach of the two REU programs has been very beneficial to both of them. We summarize approaches to recruitment, selection and creating an environment conducive to cohesive and motivated community of young researchers. While the majority of student experiences have been through individual projects, we have also experimented with small teams headed by a single adviser. Because the teams can exploit the combined strengths of its members, they can accommodate a greater diversity of individual student skills and experiences. Such projects tend to provide opportunity for open-ended exploration within the context of a general goal. Some of the projects are specifically focused on developing low-cost, hands-on demonstrations for teaching glass science to others through a more experiential and intuitive approach. All of these REU projects have been incorporated in an on-line collection of activities for the science education community at large, as reported previously [2,3].

For the international component of REU, we have supported glass faculty in the country, who wish to engage their undergraduate students in a glass based summer research in the lab of an international colleague. These experiences require considerable preparation and individual attention. Here we discuss the challenges and successful strategies to deal with both the international and domestic programs.

INTRODUCTION
The Research Experiences for Undergraduates (REU) programs are designed to support direct and active engagement of undergraduate students in areas of research funded by the National Science Foundation (NSF). For many students the REU provides their first experience with research and it can greatly influence their future opportunities and decisions. REUs exist both as individual supplement grants and as group site grants, the latter being our focus here. For 2014 a total of 652 different REU Site programs were listed by NSF [4], covering a wide array of both science and engineering disciplines and special topics. Among them 75 programs
were materials related, and therefore funded by NSF’s Division of Materials Research (DMR) [5], with the majority being hosted by either a MRSEC (Materials Research Science & Engineering Center) or a Materials Department. Out of these 75, only two programs offer an international research experience, of which our program is one.

Our International Materials Institute for New Functionality in Glasses (IMI-NFG) was initiated in 2004 with the dual mission of facilitating international research collaboration in glass, and providing education and training for the glass research community and future scientists. Included in that goal was the establishment of an REU program focused on glass science comprising both a domestic and an international component. This program is unique on both counts, i.e.: (1) it is the only REU focusing on glassy materials, and (2) it is the only materials program with both domestic and international REU components.

Glass is a ubiquitous material with applications across a very wide range of field (from architecture to energy, communications, electronics and biomaterials, to mention just a few). Whereas the traditional glass industry is well established, we emphasize the evolving role that glass plays as an enabling material for a host of applications in other fields, such as harnessing solar energy, lighting, tissue regeneration, wound healing, etc. Consequently, we place strong emphasis on a cross-disciplinary approach to which glass provides a unifying theme of our program. Thus, the research topics and our project advisers come from a broad range of departments including biology, physics, electrical, environmental and civil engineering, as well as materials science. This cross-departmental approach has helped foster new collaborations across university departments, and brought non-glass researchers into the field of glass.

In this paper we summarize the progress our REU programs and report on the lessons learned during past ten years of IMI-NFG. An article highlighting several individual REU participants was published last year in the Bulletin of the American Ceramic Society [6]. Here we provide a more comprehensive review of the overall program, both domestic and international.

**PROGRAM DESCRIPTION**

**Overview of the IMI-NFG REU Programs**

Our REU program is composed of several distinct yet complementary elements which partition primarily between the international and domestic programs. While there is only one format for the international program, the domestic program is composed of several components. First and foremost is our “Domestic Summer REU Program” hosted primarily at Lehigh University, along with a smaller component hosted at Penn State University. Strengthening of cross-disciplinary interactions among the faculty at Lehigh and Penn State described above is incorporated as one of the goals of the domestic REU programs. The domestic program at Lehigh University has yet an additional component, which we refer to as the “Regular Term REU”, which enables a few of Lehigh students to participate in glass research throughout the regular academic year. This Regular Term program provides a certain level of continuity in the research experience for selected undergraduates on campus. This is essentially run as an individual REU program that NSF extends to single PI projects – we will not discuss it any further. We will focus rather on the larger, domestic summer Site REU program, which is open to students across the US and thus holds greater relevance to the materials community at large.

Like the domestic summer Site REU program, our International REU program is open to highly qualified undergraduates from any US University to participate in summer research at a hosting institution abroad. For this program the faculty at the student’s home university
participates in organizing the student’s international research exchange, thereby strengthening an international collaboration between the sending and hosting organizations.

Over the past decade our programs have trained collectively 117 undergraduates in 150 separate research experiences. The overall size and breakdown within each of the above categories are captured in Table 1. Some of the students have participated in multiple projects. In the sections to follow we will discuss each of the programs and the lessons learned separately. Common areas such as recruitment will apply to both the programs, which are presented in corresponding sections.

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<tr>
<th>Table 1. Ten Year Breakdown by Category</th>
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<td>Category</td>
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<td>Domestic -total</td>
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<td>Summer LU</td>
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<td>Regular Term</td>
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<td>International -total</td>
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<td>Total # students</td>
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The Domestic REU - A Collaboration between Group REU Programs

The Domestic Summer REU Program at Lehigh has been the core and largest component of our REU program. From inception, we have had the fortune of partnering with another, pre-existing REU program at Lehigh University, the Physics REU, enabling us to share many crucial administrative aspects as well as housing, seminars and social events. This combined glass and physics REU effort typically hosts approximately 25 students each summer, of which the IMI-NFG students comprise about one third. We provide many opportunities for the students in the two REUs to interact with each other on both a professional and a social level. Establishing a community of scholars in conjunction with their individual research, is a priority shared by both REUs, and we know from student evaluation that it is a very important component to their overall feedback (see evaluation section below). This larger group REU provides a much richer experience for the student than the more isolated, individual REU experiences.

All the students live together in a single housing facility, providing an environment for significant social interaction among this population on a daily basis. All students in this combined program gather weekly for a Friday seminar with topics from physics and materials science.

The schedule for the first week includes safety training and library research orientation for all students. There are multiple organized events to facilitate social exchange at the beginning, including a pizza ice-breaker meal on the evening of move-in day, kick-off picnic during the first weekend and few other events spread across the 10 week period. A glass blowing workshop is organized by the IMI-NFG as an option for the students. Generally students begin to organize events on their own after the first week or so. IMI-NFG provides a webpage with activities to explore in the local area. Usually one of the students initiates a Facebook group to facilitate communications. Overall the community experiences help support our primary education and research imperative. And at the end of the program, all students present a summary of their work to the group. The student presentations keep the students focused on their research progress throughout the program. The joint programming has been very beneficial for both REU programs.

IMI-NFG REU at Lehigh has hosted 75 research experiences over the last decade, with our US students coming from 59 different universities covering 21 US states and even Canada.
The REU program at PSU runs somewhat independently of the LU based program described above, except that PSU select students from the same pool of online applicants as well from their own internal applicants. Earlier we tried to provide some interaction between the glass REU students enrolled at LU and PSU, but the 170 mile separation rendered it impractical for a ten week program. Distance clearly limits the sense of community afforded by the co-located IMI-NFG and Physics programs.

The International Glass REU Program

Our International REU (IREU) Program provides an opportunity for highly qualified undergraduates from any University in the US to participate in glass related research overseas. It is not a standard REU, but functions more like an international research partnership between a US and an overseas group, where the US faculty proposed to send one of his/her students to the overseas collaborator. Once the US professor and student have proposed an exchange, we evaluate its appropriateness for support from IMI-NFG. We also make sure that essential issues like passport, housing, visa, travel, etc. are properly addressed before the final approval. To date IREU has placed 27 UG students to 13 different countries including: Brazil, China, Czech Republic, UK, France, Germany, Greece, Hungary, India, Japan, South Korea, Portugal, and Spain. The student participants were predominately (62%) from material science departments with the rest coming from physics or electrical engineering, although all had a US adviser directly engaged in materials related research.

Challenges, Lessons Learned and Successful Examples

The IREU programming faced many challenges, most notably due to organizing the hosting, housing, international travel, local transportation, etc. from a distance. For the student, there are issues of different language, culture and research expectations. The applications for this program have been limited; some believe it is because US students are reluctant to leave the comfort of their home and language. However, we find that certain advisors consistently manage to get their students excited about taking on these challenges, and these tend to be advisors who are themselves familiar and comfortable with the host location to convey the excitement. These advisers also want to be part of the collaboration. We find that students with no international experience are much less reluctant to live abroad if they can go with another student. Likewise having multiple students travel to the same location minimizes much of the administrative burden associated with individual placements. Student comfort and research continuity can also benefit from reverse visits, where students from the overseas lab spend time at the US location.

Figure 1. REU students encountering both glass science and glass art at the Glass Arts Workshop organized by the IMI-NFG.
Such a partnership model for the REU is consistent with the underlying mission of the IMI-NFG, although outside the standard REU model.

One of our most effective IREU placements has been from Austin Peay State University in Tennessee, where the two faculty have strong ties with hosts in Eastern Europe and Brazil. Over the last three years, they have initiated REUs for four separate students to the University of Pardubice, with which they had strong pre-existing partnership. One of the APSU faculty arranged his own summer research to be in the Czech Republic and Poland, allowing some overlap with his students during their REU. This year another faculty member at APSU initiated a dual IREU for two of his students to Federal University of São Carlos in Brazil. All of the APSU generated IREUs have produced high quality work, including multiple publications. We believe this model should be considered as an effective model for future IREU programs.

Program Advertisement, Recruitment and Selection

Applications to our REU programs are received through two main channels: the online applications submitted on the IMI-NFG website, and candidates referred by the Physics REU with explicit interest in materials science as their area of interest. To encourage minority participation, we have conducted regular recruitment trips to three HBCUs in Alabama, representing both the IMI-NFG and the Physics REU programs. Likewise the Physics faculty recruit for us at several HBCUs in Georgia. The recruitment trips have had a significant impact on the minority participation in our programs. In addition to these yearly recruitment trips, IMI-NFG faculty taught several glass courses at Tuskegee University. This long term involvement has helped maintain a channel of interest in Lehigh’s glass and physics programs. The faculty-to-faculty relationship is essential for such long-term participation of minority students.

During the initial years we received very few applications through our website. Outside of those generated from the recruitment trips, we relied heavily on applications received through the Physics REU and from Lehigh’s MS&E department. However, the applications coming through our website have grown steadily throughout the program years. Indeed during the last four years we received far more high quality applications through our website than the positions available for the domestic summer program (typically, 8 per summer). Having an abundance of qualified applicants is essential to achieving a diverse and balanced student population, especially women and minorities in the program. During the application review process we attempt to match student profile with the needs of previously identified projects, and keep an eye for other qualities such as leadership that may strengthen the overall group cohesion. GPA is considered important but certainly not the only consideration. The review and selection process must begin early and is one of the most time consuming and important aspects of the program. As a result of dedicated efforts on recruiting, for the summer REU program at Lehigh we have been able to achieve a 46% female and 21% minority participation during the ten year period.

For IREU the number of faculty sponsored applications remained the limiting factor for most of the program, but during the last two years we had 6 and 5 highly qualified selections respectively, reaching the target. Program awareness took several years to develop and achieve the target level of all the components of our REU programs at this point.

Materials Education Projects with Focus on Building of Apparatus

In the traditional REU a student is paired with a research faculty’s lab where (s)he participates in some aspect of the advisor’s “forefront” scientific research program. The IMI-NFG also wanted to create a few projects with a focus on materials education, where the
emphasis is more on the exploration of the principles of glass science and research in easily accessible glassy systems using a low-cost approach, including home-built apparatuses. The goal has been to engage the students in the design and development process, while creating a collection of interrelated experiments that could provide a low-cost approach to teaching glass science through hands-on engagement. By designing the apparatus and associated equipment for the experiments the student is thrown into the full experience of the scientific and engineering challenge. We typically use sugar glass, a.k.a. hard candy, as our model glass system that eliminated the need of working with high temperature furnaces.

Through these projects we have built an entire mini-curriculum in glass science, incorporating quantitative experiments including such topics as: surface and bulk crystallization, DTA for thermal analysis, electrical conductivity, thermal conductivity, photo-conductivity, carbon nanoparticle based fluorescence in sugar glass, etc. All the experiments provide a quantitative, yet accessible, approach to exploring the same phenomena as the one encountered with regular glasses but at a much higher temperature. Every one of these REU projects has been completed with sufficient technical rigor to be presented at national conferences. Details of these presentations are available on the IMI-NFG website [7] and highlights have been summarized in two separate reviews [2, 3]. Because these projects emphasize a more hands-on and empirical approach, they do not require the student to have any specialized background. Thus they can accommodate students without strong materials credentials, although we do look for a strong level of enthusiasm and commitment to science and discovery. In general, the build-it-yourself approach generates strong enthusiasm from our participants.

**Student Team Approach to REU**

The other approach we have explored utilizes student teams. In this case several students, most commonly in pairs, work with the same adviser on different aspects of a single project, or on different projects sharing common background skills and learning. In either case there is an economy of scale for the adviser, where he/she can provide much of the background training to all students at the same time and the students can later support each other in the reinforcement process, each bringing his/her individual skills and understanding into the team. Students often find it more comfortable to approach one another with their questions and uncertainties, and they often prefer to re-explain concepts to each other before bringing unresolved concerns back to the adviser. We began utilizing this approach in 2010 for two separate group projects, one within our glass education program, which included four students in the initial training on instrumental design and data acquisition, and a pair of students in a separate project to measure the mechanical properties of a porous bioactive glass material. In the former, we clearly witnessed the students helping one another in the joint tutorial phase and that group support continued as they moved into their separate projects.

The latter pair of students was regularly seen together and actually did a joint presentation at the end of the summer, one focusing more on the synthesis of the material and the other on the mechanical measurements. Both of these initial team oriented projects were so successful that we have adopted this model for seven different student pairings in subsequent projects, including four with IREU students. In this case, the pairing has been especially useful to alleviate some of the anxieties that US students can experience traveling for the first time to a foreign country, language and laboratory. While mentoring a pair of students can initially be somewhat demanding on the adviser, they are likely to require less direction as the training progresses, and
students have responded very well to the cooperative approach. Overall this model has been very successful.

PROGRAM EVALUATION & IMPACT
At the end of the summer program we conduct a two-page, sixteen question evaluation and a 20-minute exit interview. The questionnaire provides easy to tabulate information while the face to face interview provides valuable insight and interpretation to the numbers. The questionnaire evaluates many aspects of the overall program management; we limit our focus to the ones most relevant to the overall impact. The most important findings to pass on from that collective feedback are summarized below.

Research & Learning Experience:
Overall the IMI-NFG REU Program received very positive reviews, especially during our later years. In terms of the organization and quality, participants felt the program was very good and all agreed that they learned a lot about material science from their research and experienced a new understanding of how research is carried out. When asked to rate the overall quality of their research participation, student from the last two years rated the program at 4.81 out of 5 as highest. When asked if they would recommend the program to others, we received a 4.95 rating. For most students, the REU was their first true research experience. Those new to research typically experience some struggle for first few weeks, as they adjust to the less-structured format and open-ended nature of research compared to a standard lab. These students also relate their “ah ha” moment when they realize they can figure many things out for themselves and that results slowly begin to follow.

Community of Scholars Benefit:
Almost every student indicated that the community aspect of the REU program was just as important as the research experience itself and ranked the social aspect as generally “excellent”. The shared housing arrangement was viewed as an important focal point for social interaction and getting to know one another. Students expressed interest in learning about each other’s projects and several indicated that it was helpful to share some of their frustration and early feelings of being “lost and confused” with others in the house, and realizing that they were not alone in the experience.

Future Career / Graduate School:
The students in our program are already highly motivated towards a career in science and engineering. When asked if the program made them more or less likely to pursue a career in these fields, fully 50% selected “never and doubt” while the remaining 50% averaged an outstanding 5 out of 5. On the other hand, many students come into the program uncertain about their specific post-graduation plans, i.e. graduate school vs. industry. The student surveys indicate that the REU experience was very helpful in moving them closer to one opinion or the other. More commonly the previously uncertain students moved towards the graduate school choice, while others come to the conclusion that research is really not for them.

Student Presentations & Publications
For all of our REU projects the primary objective has been to train and engage US students in the research experience. Often the project is exploratory and there is no expectation for publication. On the other hand, for many students the results have been significant enough for subsequent presentation as posters or talks at national meeting. Since 2009 more than 40 such
national presentations and publications have resulted, representing more than 50% of the student projects during this same period. Several projects have gone on to achieve awards of distinction for their work, such as, Berbano and Mohrmann for best student speaking awards at 2010 MS&T Meeting, and Korngruen for the first prize at the 2012 GOMD poster competition.

CONCLUSIONS

We have described our decade long experience of running an REU on glass with both domestic and international components. For the domestic site collaboration with another REU on campus proved to be synergistic and very helpful, providing for the sharing of the considerable overhead of program organization and management. Developing an effective REU program can take several years to refine, and there is much to learn from the experience of others. Creating an environment to support a sense of community among our scholars was perceived as a very important part of the overall student satisfaction and professional experience. We have also introduced two new approaches for the REU experience. One is to include projects related to materials education, focusing on creating low-cost, student built apparatus for exploring glass science; the other utilizing a student team approach with advantages to both the student and the adviser. For IREU we strongly recommend a model that supports developing ongoing partnership between a US university and a collaborating international host.

ACKNOWLEDGEMENTS

We would like to express our gratitude to the Dr. John Huennekens who guided the physics REU for more than two decades and provided considerable mentorship to us from the outset, and to all of the advisers who mentored our students. This work is supported by the International Materials Institute for New Functionality in Glass through an NSF Grant (DMR-0844014).

REFERENCES

1. The website for the IMI-NFG is www.lehigh.edu/imi.
5. From NSF’s Division of Materials Research (DMR) website at [https://www.nsf.gov/crssprgm/reu/list_result.jsp?unitid=5052 ]
7. See the education and outreach section of the IMI-NFG website at www.lehigh.edu/imi.

On the date this paper was written, URLs or links referenced herein were deemed to be useful supplementary material to this paper. Neither the author nor the Materials Research Society warrants or assumes liability for the content or availability of URLs referenced in this paper.