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Accelerated Learning: Undergraduate Research Experiences at the Texas A&M Cyclotron Institute

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Abstract

The Texas A&M Cyclotron Institute (TAMU CI) has had an NSF funded Research Experiences for Undergraduates program since 2004. Each summer about a dozen students from across the country join us for the 10-week program. They are each imbedded in one of the research groups of the TAMU CI and given their own research project. While the main focus of their effort is their individual research project, we also have other activities to broaden their experience. For instance, one of those activities has been involvement in a dedicated group experiment. Because not every experimental group will run during those 10 weeks and the fact that some of the students are in theory research groups, a group research experience allows everyone to actually be involved in an experiment using the accelerator. In stark contrast to the REU students' very focused experience during the summer, Texas A&M undergraduates can be involved in research projects at the Cyclotron throughout the year, often for multiple years. This extended exposure enables Texas A&M students to have a learning experience that cannot be duplicated without a local accelerator. The motivation for the REU program was to share this accelerator experience with students who do not have that opportunity at their home institution.

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1. The ability to get real research experience with world-class faculty and facility

“Being from a small liberal arts college, my opportunity to get significant physics research experience is basically nonexistent. Having the opportunity to come to the Cyclotron Institute and work on an actual research project at a research university greatly increased my excitement about choosing physics as my field of study.”

The above is a quote from an REU student who participated in research during the summer at the Texas A&M University Cyclotron Institute (TAMU CI). The overall objective of the Research Experiences for Undergraduates (REU) program at the TAMU CI is to bring in a diverse group of students from throughout the US who do not have access to these types of facilities at their home institution. Students become engaged in an interesting research experience, and mentored in their growth as young scientists.

The intellectual focus of this REU program is the pursuit of answers to the question of **“How does the physics of nuclear matter shape our world?”** Nuclear science at Texas A&M University lies jointly within the departments of physics and chemistry and takes significant advantage of the local cyclotrons. The Cyclotron Institute at Texas A&M is a Department of Energy (DOE) Nuclear Physics Center of Excellence. It is jointly supported by DOE and the State of Texas and is a major technical and educational resource for the state and the nation. Internationally recognized for its research contributions, the CI provides the primary infrastructure support for the University’s graduate programs in nuclear chemistry and nuclear physics and the NSF nuclear science REU program. As pointed out in the 2015 Long Range Plan for Nuclear Science it is in the best interest of the nation, in general, and the future of nuclear science, in particular, to expand the community of undergraduate students to whom research opportunities are available. We believe that the best mechanism for making these research opportunities available to students from throughout the US is by hosting an NSF REU program at facilities such as the TAMU CI. As a consequence, we have hosted a successful NSF-REU program in nuclear science for the past 13 years.

Targeted student groups include those from institutions without a nuclear facility and hence a limited ability to engage in this type of research at their home institution. We specifically encourage the participation of women and students of diverse ethnic/racial backgrounds. In the past three years 83% of our students have come from non research-intensive schools. Minorities participate in the scientific workforce at levels far below those in the general population [1,2]. To insure the continued vitality of the scientific enterprise and to meet our national need for a technical workforce we need to increase the participation of groups that have been traditionally underrepresented in the sciences. Studies in physics [3] indicate that students of all ethnicities that come from smaller schools without Ph.D. programs feel less prepared in math and physics and are less likely to attend a graduate or professional school than their peers in large Ph.D. granting departments. In a survey [4] of NSF funded undergraduate research participants, it was shown that the experience increased the likelihood of the student’s expectation that she or he would pursue a Ph.D. in a STEM field. This increase in expectation was larger for Hispanic and Black students than for White students. Therefore, undergraduate research experiences can be quite helpful to students from any small school, but particularly for minority students.

1.1. What students gain from research as undergraduates

The number of schools that teach undergraduate nuclear chemistry and nuclear/particle physics courses is decreasing. Therefore, it is only through programs such as the one described here that many of these students can be exposed to nuclear science, thus making it a viable career choice for them. If we are successful, the result will be a cohort of students that are more knowledgeable about nuclear science and also better prepared to engage in independent problem solving activities while becoming excited about furthering their education beyond their undergraduate degree. Students gain lots of skills as a result of undergraduate research experiences including:

- Technical skills
- Creative problem solving
- Scientific communication skills
- Dealing with frustrations / perseverance

- Self confidence
- Time management
- Project planning
- Working within a collaboration
- Leadership development

1.2. TAMU REU experiences

The primary activity of the students is involvement in the research activities of one of the nuclear science research groups. In addition to their research project there are a number of other activities that are provided for professional development and to ensure that students have a rewarding experience, including: an initial orientation, a weekly lecture series by on-site faculty, an outreach activity, a career day, weekly student lunches, an end of summer symposium and a recognition dinner. Each of these events is detailed below.

- **Individual research projects**
- **Group experiment**
- **Structured educational activities**
 - *Faculty lectures*
 - *Educational field trips*
 - *Outreach activity*
 - *Machine shop class*
- **Scientific communication**
 - *Poster presentations*
 - *Oral presentations*
 - *Written presentation*
- **Professional Development**
 - *Career day*
 - *Lunch discussions*
- **Social events**

1.2.1. Typical research projects

Within the broader context of the Texas A&M research group's activities each student will have a project that is his or her own. In all cases students start out working closely with the faculty mentor and other members of the research group. As the student progresses, she or he performs with increasing levels of independence, as her or his preparation and progress deem appropriate. Examples of recent research projects include:

- "Developing a Universal Parameterization of Dilepton Emission Rates"
- "Studying the nuclear pairing force through $^{18}\text{O}(^{26}\text{Mg}, ^{28}\text{Mg})^{16}\text{O}$ "
- "Theoretical Predictions of Giant Resonances in ^{94}Mo "
- "Monte Carlo Simulations of Freeze-out with Momentum Constraints in High Energy Nuclear Collisions"
- "Profiling CsI detectors"
- "Assembling, cleaning, and testing a unique open-ended cylindrical penning trap (TAMU TRAP)"
- "Analyzing chiral condensate dependence on temperature and density"
- "Precise Measurement of αT for the 39.76-keV E3 transition in ^{103}Rh : Further Test of Internal Conversion Theory"
- "A Study of the quality of CsI detectors and pulse-shape discrimination of scintillators for α particles, γ particles, and neutrons"
- "Reconciling Giant Resonance Data"
- "Characterizing BaF2 Detectors for use in Gamma Ray Detection"
- "Thallium extraction from hydrochloric acid media into a deep eutectic using bis(2-ethylhexyl) phosphate "

1.2.2. Initial Orientation and Weekly Faculty Lecture Series

Since most of the students have a limited background in nuclear science (NS), the students are given a set of introductory lectures during the first week of this program. Our first cohort of REU students requested this up-front nuclear science orientation and its value has been reaffirmed by successive cohorts. Additionally, we have a weekly discussion led by various faculty members on different aspects of the field. In this way students not only gain an in-depth knowledge of the area of their specific research project, but they also gain a broader knowledge and perspective of NS in general. This weekly series of lectures has been a constant part of this program for 13 years and students have responded quite well. A list of the 2016 lectures follows:

- Dr. Che-ming Ko: Introduction to Atomic Nuclei
- Dr. Carl Gagliardi: What Makes the Proton Spin
- Dr. Rainer Fries: The Physics of Quarks and Gluons: A Brief Introduction
- Dr. Cody Folden: The Heaviest Elements
- Dr. Dan Melconian: Fundamentally Cool Physics with Trapped Atoms and Ions
- Dr. Saskia Mioduszewski: Probing High-Temperature Nuclear Matter at RHIC
- Dr. Greg Christian: Nuclear Astrophysics: Understanding the Big by Studying the Small
- Dr. Grigory Rogachev: From Nucleon-Nucleon Interaction to the Physics of Stars
- Dr. Jeremy Holt: Nuclear Microphysics of Neutron Stars and Core-Collapse Supernovae

In addition, all students receive basic ethics training as part of the orientation week. Texas A&M is a member of the Collaborative Institutional Training Initiative (CITI). CITI hosts a web-based course entitled “Physical Science Responsible Conduct of Research.” All of our students are required to complete this course as part of orientation.

1.2.3. Example group experiment

A dedicated group research experience allows REU students to be involved in an experiment using the accelerator, since every experimental research group does run during those 10 weeks in the summer. Furthermore, some of the REU students are in theory research groups. One year the experiment revolved around the production, separation and study of new beams of radioactive ions – in particular, ^{20}Na and ^{20}Mg . The ^{20}Na was predictably easy and abundant, but with a complex decay. The ^{20}Mg was more difficult, but needed for a planned experiment. This experiment was related to the work of the host group: nuclear astrophysics – use of nuclear physics to understand the origin of chemical elements, to test models for the evolution of the Universe.

- Goals were to get the students acquainted with:
 - Experimental techniques as applied in a large nuclear physics lab
 - Realities of scientific work: interesting---but not easy; round-the-clock; trial-and-error; limited resources; international collaboration
 - Team work: students were divided into 3 shifts for 24 hrs. work, under the direction of TAMU graduate students and post-docs with one scientist coordinating
- Experiment chosen to present many faces:
 - Work with complex installations: K500 and MARS
 - Lesson: all parts must work 100%
 - Use of electric and magnetic fields to transport and select energetic beams
 - Lesson: charged particle in E, B fields
 - Detection of nuclei and their radiation
 - Lesson: interaction of radiation with matter; detectors
 - Work with electronics and data acquisition systems

1.2.4. Street Physics



In 2012, the Cyclotron REU students put together a set of hands-on activities and took them to the street – literally. An outreach activity called Street Physics was born and has been a part of our program ever since. The local community hosts a monthly event called First Friday where many hundreds of people fill downtown to enjoy art, music and each July – science. During the July First Friday event, our REU students bring numerous physics and chemistry demonstrations to the sidewalks of downtown. The REU students enjoy engaging people of all ages in the fun. Often once discussions start the students end up explaining not just basic science, but also their research projects to the public. Both the public and the students have enjoyed the participation in First Friday and we anticipate this to be a continued activity. This activity has even

been highlighted in the local paper, thus increasing the exposure of the general public to the beauty of science.

1.2.5. Career Day

With a degree in nuclear science there is a diversity of career paths that are available to young scientists. We host a one-day symposium to inform students about many possible career paths. The featured speakers are established scientists that are currently in universities, colleges, national laboratories, and the private sector with the common feature that they received a graduate degree in nuclear science. Since we open these talks to the lab as a whole, Career Day has the added benefit of possibly connecting our current graduate students into positions upon graduation. Select biosketches and presentations from these are included in a web-based gallery of former students so that there is a central location for examples of what people can do with an advanced degree in nuclear science.

In addition to the lectures by current scientists, we have several other activities for the students on Career Day. We typically also arrange two more speakers, one of whom gives a presentation about the types of research in fields of physics other than nuclear at the University. The other speaker gives a presentation about the resources available for applying to graduate school as well as general tips in order to make their application process as successful as possible. Career Day also includes a luncheon where the REU students meet with current graduate students to learn more about graduate school life.

1.2.6. Welcome Event, Weekly Gatherings and Recognition Dinner

When the students arrive and begin working with their research groups it is important that they feel like members of our community at large. In order to help them feel this way we have an event in which all current members of the Cyclotron Institute gather to welcome our REU students. This is followed by a weekly mentoring lunch. These lunches are intended to guide the students and keep them on task with their posters and presentations as well as provide them a safe environment for discussions with a mentor. At the end of the summer, the students, faculty and

research group members are also invited out for a dinner recognizing the students for their work and time spent with us.

1.2.7. End of Summer Activities

The final week of the program provides students with several opportunities to build skills they will need later in their career. The University's Undergraduate Research group organizes a poster session open to all students participating in summer undergraduate research campus wide. Students presents a poster about their individual research project. We also host an in-house symposium where each student gives an APS-style oral presentation for our faculty, staff and fellow students. While not a requirement of our program, all of our students are strongly encouraged to apply to and attend the Conference Experience for Undergraduates at the fall DNP (or similarly appropriate) meeting. All posters and talks are viewable on our website. (<http://cyclotron.tamu.edu/reu-archive/>)

1.2.8. Conference Experiences for Undergraduates

The Division of Nuclear Physics hosts a Conference Experience for Undergraduates (CEU), which is a meeting within the regular DNP meeting (<http://www.uwlax.edu/ceu/>). This takes place in the fall, usually late October, and is a great time to touch base about how REU students who worked at the TAMU CI have been able to apply the skills they acquired during the summer to the rest of their undergraduate program experiences at their home institution. For instance, there is a poster session where they get to interact with the DNP community at large and gain further appreciation on how interesting and valuable their project is to the nuclear science community. The graduate school fair is a great opportunity to talk to representatives from numerous graduate programs. The activities that the students can be involved with include:

- Plenary Session - A Broad Perspective on Nuclear Physics: Where are we now and where do we go from here?
- DNP Welcome Reception
- CEU Research Poster Session
- CEU Nuclear Physics Seminar
- CEU Student Social and Reception
- Graduate School Information Session
- DNP Banquet
- CEU Nuclear Physics Seminar

1.2.9. Collaborations with National Laboratories

The Texas A&M Cyclotron Institute has enjoyed a collaboration with Lawrence Livermore National Laboratory (LLNL) aimed at measuring critical nuclear parameters of interest to both the basic science and applied science communities. This collaboration has been beneficial to the REU program as Dr. Jason Burke has given talks to the REU students about the research program and invited them to take part in experiments. This has resulted in an opportunity for the REU students to get involved in an experiment, meet and network with the scientists from LLNL and the rest of the collaboration. Three publications [38-40] that our REU students have coauthored with the LLNL scientists have resulted from these experiments in the past three years. Additionally, scientists from LLNL have given talks and hosted discussion groups about career opportunities at national laboratories.

We have recently begun to collaborate with scientists from Los Alamos (LANL) to study nuclear structure and reactions to understand the origin of the elements. As part of this collaboration, 2016 REU student Austin Townsend

was able to take part in an experiment with Dr. Shea Mosby from LANL this past summer. We anticipate this collaboration to also result in additional opportunities for our REU students in the coming years.

1.2.10. REU Summer Scholars Program

The REU Summer Scholars Program is a university-wide optional supplement to the summer research undergraduate experience which is intended to help ethnic minority students build a community and is open to all university majors. Summer Scholars are invited to attend weekly informal lunch discussions focusing on ethnic minority issues, featuring university administrators and other special guests, and a variety of topics. The 2016 list of guests and topics follows.

- “Welcome Luncheon” with Kristen Harper the Executive Director of Undergraduate Studies and Dr. Mark Zoran the Associate Dean of the College of Science
- “Leadership” with Dr. C.J. Woods the Associate Vice President of Student Affairs
- “Graduate School Experiences” with a Graduate Student Panel
- “How to Fund Graduate Studies” with Dr. Shannon Walton the Director of the Office of Graduate and Professional Studies
- “Success Strategies for Minority Scholars” with Dr. Sumana Datta the Assistant Provost for Undergraduate Studies and Executive Director of LAUNCH
- “How to Best Position Yourself for Acceptance and Funding for Graduate School Along with Expectations After Being Accepted” with Dr. Edward Tarlton
- “Graduate School 101” with Dr. Prasad Enjeti the Associate Dean for Academic Affairs for Electrical and Computer Engineering

2. Final Thoughts

In the first 13 years of the REU program at TAMU CI we engaged 156 students in research projects. Of those students 52 (33%) students were women, 24 were Hispanic students and 14 were African American students. Overall, of the students that indicated an ethnicity, 36% of the students were from ethnic minorities based on the students that indicated an ethnicity. Also 83 of our students have participated in the APS/DNP Conference Experience for Undergraduates (CEU) program and presented posters on their research with a number of other students participating in assorted other professional meetings. Research from these students has contributed to 40 papers in print in peer-reviewed journals and 4 conference proceedings where the students are listed as a contributing author. [6-49] All the posters and presentations of the students are posted on our website at <http://cyclotron.tamu.edu/reu>. The following is a quote from an REU student who participated in research during the summer at the TAMU CI:

“My time with your group also played a major role in my decision to continue on with my education and pursue a Ph.D. in Physics. Through group meetings, conferences, and everyday interactions with members of the group I gained a sense of what was expected of a graduate student, the skillset gained by continuing studies beyond classes, and recognized the freedom to follow your curiosity that a Ph.D. grants”

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