NanoJapan International Research Experience for Undergraduates: Preparing Globally Engaged Science and Engineers

1.0 Introduction

The NanoJapan: International Research Experience for Undergraduates Program, established by a National Science Foundation Partnerships for International Research and Education (NSF-PIRE) grant in 2006, is a twelve-week summer program through which twelve freshman and sophomore physics and engineering students from U.S. universities complete research internships in Japanese nanotechnology laboratories. NanoJapan tightly integrates the international experience with students' academic programs by providing hands-on opportunities to acquire technical skills and knowledge associated with cutting-edge nanotechnology research projects. The program aims to increase the numbers of U.S. students who pursue graduate study in nanoscience and cultivate a generation of globally aware engineers and scientists who are prepared for international research collaboration. The NanoJapan program is the key educational initiative of the National Science Foundation–funded Partnerships for International Research and Education (NSF-PIRE) grant awarded to the Electrical and Computer Engineering Department of Rice University and the Center for Global Education at the University of Tulsa. The program was awarded five years of funding in 2006[1] and has been renewed for another five years[2].

This paper will provide an overview and justification for the development of the NanoJapan Program, provide an overview of our program assessment and student outcomes to date, and conclude with an overview of the potential impact of the NanoJapan Program model on STEM education and international engineering programs nationwide.

2.0 Program Context

<u>2.1 The need for internationalization of STEM Education:</u> The Institute for International Education's (IIE) *2012 Open Doors* report indicates that science and engineering students still make up a relatively small percentage of the overall number of students studying abroad. In 2010/2011, the last year for which data is available, 3.5% of the students who studied abroad majored in engineering, 7.9% in the life sciences, and 1.8% in math and computer science. According to the IIE data, only 36,165 students majoring in STEM fields (undergraduates and graduate students) participated in a study abroad program during the 2010/2011 academic year, out of a total of 273,996 U.S. students overall[3].To put this data into perspective, consider just the total number of students in the United States seeking engineering degrees. According to the American Society for Engineering Education's *Engineering College Profiles & Statistics*, in Fall 2011 there were 471,730 undergraduates enrolled as full-time engineering majors at U.S. institutions[4]. Using IIE data, 9,589 engineering majors studied abroad in 2010/2011[5], or just 2% of the total number of students studying engineering in the U.S. participated in a credit-bearing international experience.

The small number of U.S. engineering and science students who pursue an international experience is particularly concerning given the importance being placed on international research collaborations in science and engineering by national agencies and professional organizations. In its 2006 – 2011 fiscal year strategic report the NSF identified as a key performance goal the need to "keep the United States at the frontiers of knowledge by increasing international partnerships and collaborations". The strategic plan went on to say that, "As science and engineering (S&E) expertise and infrastructure advance across the globe, it is expected that the United States will increasingly benefit from international collaborations and a globally engaged workforce leading to transformational S&E breakthroughs."[6] The *2010 Globalization of Science and Engineering Research* report further highlights how the data show a global recognition of the need to move towards knowledge intensive economies and the important role that science and technology plays in "generating new jobs, economic prosperity, responses to national issues and/or global challenges, and global competitiveness"[7]

The importance of placing engineering and science education within a global framework has also been highlighted by the National Academy of Engineering (NAE). In its *Engineer 2020* report it found that "to understand the full perspective engineering practice and engineering education must be considered in a global context."[8] The report also stressed the importance of engineers being able to successfully work in teams whose essential attributes include, "excellence in communication (with technical and public audiences), an ability to communicate using technology, and an understanding of the complexities associated with a global market and social context. Flexibility, receptiveness to change, and mutual respect are essential as well."[9]

2.2 Nanotechnology Research in the U.S. and Japan: From a research perspective, the United States, China, and Japan accounted for just over half of the $1.28 trillion dollars in global research and development investment in 2009. The share of Asian investment in global R&D has risen from 24% in 1999 to 32% in 2009 with Japan accounting for 11% of this total[10]. The numbers of internationally co-authored papers has also grown substantially from just 8% in 1988 to 24% in 2010.[11] These numbers attest to the growing importance of international collaboration in science and engineering, particularly with Asia.

As international partnerships, then, have become increasingly indispensable to solving major science and engineering problems, U.S. researchers and educators must be able to operate effectively in teams comprised of partners from different nations and cultural backgrounds; particularly in the emerging fields of nanotechnology research. The NSF-PIRE grant that funds the NanoJapan Program supports a U.S.-Japanese partnership exploring terahertz (THz or 1012 Hz) dynamics in nanostructures. The electromagnetic spectrum from 0.1 to 10 THz offers many opportunities to study physical phenomena, with potential payoff in numerous technologies. By combining THz technology and nanotechnology, we can advance our understanding of THz physics while improving and developing THz devices. Japanese universities are logical partners for our research and educational collaborations due to the heavy investments being made in nanotechnology research in both countries. As reported by the National Nanotechnology Initiative, the U.S. and Japan led global investment in nanotechnology research in 2008 at $1.55 billion and $950 million respectively[12]. Japan understands the urgent need to internationalize its scientific enterprise and has committed to spending $70 million over the next 10 years to attract leading scientists from around the world[13]. To further advance nanotechnology science and develop new ideas from the lab into commercial products, it is important to stimulate cooperation between these countries.

Yet obstacles to further research collaboration between the U.S. and Japan remain, primarily linguistic and cultural barriers. By breaking down these barriers, our integrated research and education program will achieve long-term scientific and societal impact, providing future generations of researchers with an understanding of both the culture, and state-of-the-art technology, in each country. This will enable the already high level of funding in both countries to have even greater scientific and societal impact, since future generations of researchers will have a better understanding of both the culture and the state-of-the-art technology in each country.

3.0 NanoJapan: International Research Experience for Undergraduates

If the international nature of nanotechnology research demands that engineers and scientists have the skills to be able to collaborate in an international environment, there is a clear need to expand and develop international programs that address the unique needs of engineering and physics students. Historically, these students have had fewer international opportunities that allow them to pursue coursework or research abroad that is directly tied to their degree program. The NanoJapan program, discussed in depth in this paper, is an innovative response designed to address this need by attracting undergraduate students to the emerging areas of electrical engineering and the physical sciences, especially the study of nanotechnology. By involving and training students in cutting-edge research projects in THz nanoscale science and engineering, this program aims to increase the number of U.S. students who choose to pursue graduate study in this field, while also cultivating a generation of globally aware engineers and scientists who are prepared for international research collaboration.

3.1 Program Objectives: The NanoJapan Program is a 12-week summer program that places first- and second-year undergraduate science and engineering students from U.S. universities in research internships with Japanese nanotechnology laboratories. The objectives of the education program are to : i) to cultivate an interest in nanotechnology as a field of study among college students; ii) to cultivate the next generation of graduate students in nanotechnology; iii) to add to the skill set of active nanoscience researchers; iv) to create students who are internationally savvy and have a specific interest in and knowledge of Japan; and v) to educate students in culture, language and technology, in order that they may be more effective when addressing global scientific problems.

3.2 Program Model: NanoJapan, like all PIRE-funded projects, is characterized by a tight integration between the research and education programs. The education program is informed by Parkinson's characteristics for a 'globally competent engineer,' in that it encourages students to appreciate other cultures, develop proficiency working in cross-cultural teams, communicate across cultures, practice engineering in a global environment, and evaluate ethical issues arising from cultural differences[14]. The program model is described below:

Intensive Japanese Language & Culture Orientation: Students complete a three-week orientation program in Tokyo that introduces them to nanotechnology research and the competencies required to work successfully in the global science community. Since most of the NanoJapan participants have not had previous experience in Japan, the students complete 45 hours of intensive Japanese language instruction. Beginning students are taught by language school faculty and intermediate/advanced language students are taught by the PIRE Japanese Language Director, a Japanese language faculty member at the University at Buffalo. Additionally, students participate in a colloquium on the history and culture of Japan, taught by local Japanese faculty. Finally, they participate in a seminar series that introduces them to nanotechnology research that has been taught by the US and Japanese THz researchers. Beginning with the 2012 program, NanoJapan students have also conducted a service visit to Minami Sanriku, a community just outside of Sendai that was devastated by the Great East Japan Earthquake and Tsunami in March 2011. The goal of the orientation program is to provide participants with the basic language and intercultural communication skills that give them a firm foundation upon which they can build during their research internships.

International Research Experience (IRE) in Nanotechnology: Students are assigned to leading nanotechnology labs throughout Japan for eight week summer internships where they conduct hands-on research in the field of THz nanotechnology research. Student research projects are developed by the U.S. research team in collaboration with the Japanese host laboratories and each U.S. students is co-advised by both a Japanese and U.S. PIRE research professor. Each NanoJapan student is assigned to a single project, and while there may be other NanoJapan students in the same university or host city, they will be the only NanoJapan student working on that particular project. NanoJapan students are mentored on a day-to-day basis by a Japanese graduate student or post-doctoral mentor, mirroring the experience of being a graduate student working on an international research collaboration. Previous NanoJapan host labs include PIRE researchers at Osaka University, The University of Tokyo, Tokyo Institute of Technology, RIKEN, the National Institute of Materials Science, Chiba University, The University of Kyoto, Okinawa Institute of Science and Technology, Shinshu University, Tohoku University and Hokkaido University.

The primary language used throughout the international research experience is English, though NanoJapan students draw upon the Japanese language skills attained through the orientation program both in and outside of the lab. All Japanese PIRE research professors speak English and the Japanese graduate student mentors must be able to speak English with the U.S. students, providing them with essential practice in the language they need most in order to participate in the international science community. Students have the option of continuing formal Japanese language study via any language classes that may be offered at their host university, through one-on-one tutoring or language exchanges with their Japanese research group members, or self-study supplemented by online resources provided by NanoJapan.

Mid-Program Meeting: As the NanoJapan program works with freshman and sophomore students, most of who have had limited prior research experience, the research team coordinates a mid-term meeting in Japan to “check-in” with all participants. This three-day meeting brings together all NanoJapan students along with U.S. PIRE faculty advisors to de-brief on the research and cultural experience in Japan to date. Through facilitated discussion, students share with their fellow program participants some of the challenges, frustrations, successes and best practices they have encountered as an American student doing research and living in Japan.

Nanotech Symposium: The NanoJapan students return to Rice University for the Rice Quantum Institute Summer Colloquium, where they present posters on their research experience in Japan along with other U.S. students who have completed nanotechnology-related summer research experiences at Rice University. The symposium provides an opportunity for student researchers to make professional presentations and prepare a ‘product’ at the conclusion of their summer internships.

Re-entry and career education program: The re-entry program is designed specific to the needs of young career scientists. In addition to examining issues associated with re-entry to the US, students participate in career decision making activities that help them evaluate their experience in Japan as preparation for graduate school and identify next academic, international, or other experiential programs that can advance their personal and professional goals.

Cross-cultural training: Throughout the summer, students engage in activities that are prompt intentional reflections on differences between scientific research in the US and Japan. Facilitated reflection is widely understood a best practice for encouraging cross-cultural learning during study abroad.[15] Before leaving for Japan, students participate in a one-day orientation in which they are introduced to approaches to thinking about cultural differences. The team has used a variety of techniques, but most recently used the Cultural Detectives program, in which students compare cultural values for the US and Japan and learn how to evaluate cross-cultural miscommunications. Throughout the summer, students complete weekly 'blogs' that summarize both progress with their research but also respond to questions about the culture of scientific research in Japan.

Other program logistics: All students receive a stipend funded by the NSF to partially cover their living and travel expenses. Their housing, typically in university dorms, is arranged by their hosting research labs.

<u>3.3 Program participants</u>*:* The NanoJapan Program recruits freshmen and sophomore engineering or science students from universities nationwide. As the program is funded by the NSF, to be eligible to apply students must be a U.S. citizen or permanent resident. Since 2006, 106 students have participated in the program, representing 37 different U.S. institutions including one Historically Black College or University, three community colleges, liberal art colleges, and a wide range of public and private research institutions. (Twelve additional participants will be selected to participate in the 2013 program by early April.) The NanoJapan Program has a strong track record of recruiting underrepresented STEM students, particularly women. Thirty-five percent of participants have been women and 15.1% represented diverse ethnic group in STEM fields. The representation of women within is particularly impressive given that National Science Foundation data shows that in 2010, the last year for which data is available, female undergraduate students earned just 16.98% of engineering and 20.41% of physics bachelor's degrees conferred. [16]

The decision to target students early in their college career was a response to the low rates of participation in study abroad by STEM majors. The program is designed to be a 'catalyst': the goal is to introduce students to research and international study when they are freshmen and sophomores so that they may choose to continue language study, seek other domestic research experiences for undergraduates, or study abroad again, based on what the learn from this program. For many students, the program represents their first experience conducting research and first exposure to Japan. Many of the students are attracted first to the NanoJapan program because it is an academic research program. Most have also indicated that they consider this their best alternative to a traditional study abroad program, which they would be unlikely to pursue since it would require them to miss a regular semester of courses.

4.0 Program assessment

The program outcomes are assessed using a combination of quantitative and qualitative methods on the following dimensions: student attitudes towards the engineering profession; Japanese language proficiency; intercultural sensitivity and competency; and career choice.

4.1 Attitudes*:* All participants complete PIRE Participant Questionnaires, an assessment tool developed by the NSF to measure outcomes for all PIRE programs. The PIRE Questionnaire specifically measures participants' attitudes towards international research and the perceived impact of the PIRE project on their career goals. Of the 64 NanoJapan students who completed the PIRE Questionnaire, 80% strongly agreed that the international dimension of the research project was an important factor in my decision to join the project; 88% strongly agreed that foreign collaborators can provide valuable contributions to US science projects; and 53% agreed that the cultural context of science has an impact on how the research is conducted.

The responses by NanoJapan participants no doubt reflect a strong selection bias – the students who apply for the program do so because they desired to participate in an international research experience. The PIRE Participant Questionnaire should not be considered a measure of the impact of the NanoJapan Program. Rather, it does describe the attitudes of students who are selected for this type of experience and demonstrates that an international dimension to a research experience can be a very important factor in recruiting students to participate in scientific research.

4.2 Language proficiency*:* The students' progress with Japanese language is assessed using the Oral Proficiency Interview, a valid and reliable measure for assessing how well a person speaks a language. The OPI is administered by a trained rater who completes a 20-30 minute face-to-face or telephonic interview with the examinee. The interview is interactive and continuously adapts to the interests and abilities of the speaker. The speaker's performance is compared to the criteria outlined in the American Council for Teachers of Foreign Languages (ACTFL) Proficiency Guidelines – Speaking . We administered the OPI as a post-test to all NanoJapan students. The chart below summarizes the results for the 80 NanoJapan students who have not previously studied Japanese.

Rating	**Students (n=69)**
Novice Low	10
Novice Mid	37
Novice High	25
Intermediate Low	6
Intermediate High	2

Among the 80 students with no previous Japanese language experience, 46% were evaluated on the Oral Proficiency Interview at a Novice Mid (roughly equivalent to 150 instructional hours) and 31% at a Novice High (roughly equivalent to 270-300 instructional hours) by the end of the summer. This is significant since the students complete only 45 hours of formal instruction though most do continue with self-study throughout the rest of the summer.

Research on the gains by STEM majors studying a foreign language is scarce, and our analysis of the reasons for the impressive progress by the students is anecdotal. Students are immersed among Japanese speakers and many students describe themselves as highly motivated to learn Japanese. One study that assessed features of study abroad programs that influenced student language learning concluded that in programs with orientations that included a cultural component, as does NanoJapan, students demonstrated greater improvement in their oral proficiency at the end of study abroad.[17]

4.3 Intercultural Competency*:* We utilized the Intercultural Development Inventory (IDI) to assess intercultural competency of NanoJapan participants. The IDI is theoretically grounded in Milton Bennett's "Developmental Model of Intercultural Sensitivity," a frequently-cited developmental model that identifies six progressive stages through which individuals pass in adapting interculturally. The results of the IDI place an individual at a point along this six-stage developmental continuum, from ethnocentric to ethnorelative. The stages of the DMIS are denial, defense, minimization, acceptance, adaptation, and integration.[18] While the IDI does not measure learning specific to Japan, it does provide reliable and valid measure of an individual's ability to operate effectively within a different cultural context. We administered the IDI as a pre and post-assessment to all NanoJapan students.

We did not find significant changes along the IDI's developmental continuum in the scores of the NanoJapan participants, which may be due to the short duration of the NanoJapan program. Of the 98 students who completed IDI pre-tests, 53% demonstrated minimization on the DMIS scale, a tendency to minimize differences between cultures, and a typical score for college students preparing for study abroad. The mean post-test scores showed a small and statistically insignificant reversal. Post test scores indicated that 52% of the respondents still demonstrated a minimization score at the end of the program. Interestingly, a similar research program based in Asia, the Pacific Rim Experiences for Undergraduates (PRIME) project, reported nearly identical IDI results for participants in their summer research program.[19]

However, in comparing the IDI results with student self-reports on the PIRE Participant Questionnaire, students report significant gains in intercultural learning. As a result of their participation in NanoJapan, 85% of participants report that "Foreign collaborators can provide valuable contributions to U.S. science projects" and 76% strongly agree or agree that the "Cultural context of science has an impact on how the research is conducted." As discussed above, while the PIRE Questionnaire cannot be interpreted to measure the impact of the program, students *perceive* that the program has affected their intercultural learning. In follow-on qualitative studies conducted with all participants at least one year following participation in the program, students indicate that their NanoJapan experience significantly affected their understanding of collaboration in scientific research; their understanding of the research process itself; and the differences between the research in the U.S. and Japan.

4.4 Career impact*:* Perhaps our most compelling outcomes data is with regard to post-program activities. A goal for the program is to encourage students to pursue graduate study in the physical sciences. Of the 106 program alums, 72 percent indicated at completion of the program they were likely to pursue a career in science and engineering, a percentage that tracks closely with actual program results.

The NanoJapan Program Alumni have an impressive track record with regard to graduate studies related to nanotechnology. Of the 106 undergraduates who participated in NanoJapan from 2006 – 2012, 35 are still pursuing their undergraduate degree, 48 are currently enrolled in Master's or Ph.D. programs in STEM fields, five have completed Master's degrees in STEM fields, 15 are pursuing industry careers in an engineering, science, or technical field, and one is currently enrolled in an MBA program. We do not have updated information for eight past participants. Among these students 7 have received NSF Graduate Research Fellowships, one has received a Hertz Fellowship, and one has received a Churchill Scholarship to pursue graduate study at the University of Cambridge in micro- and nanotechnology. One alumna was selected for participation in the 2012 NSF East Asia Pacific Summer Institute. Among the 3 community college participants, one has transferred to a B.S. program in Biomedical Engineering at the University of Texas, San Antonio, one completed a bachelors and master's degree at the University of Rhode Island and is now applying to Ph.D. programs in mechanical engineering, including an English Ph.D. program offered by the University of Tokyo. The third community college student pursued a professional engineering career.

In the Fall of 2012, the researchers conducted a qualitative program assessment on long-term impact of NanoJapan with all alumni from 2006 – 2011, a total of 94 students. The assessment was not sent to the 2012 students as they had only recently returned from Japan. Thirty students, or 31.9% of alumni surveyed responded. The students reported the following themes when asked about the impact of the program on their career goals:

- *Enhanced confidence as a researcher:* Students reported that the experience of conducting nanotechnology research improved their self-confidence working in a lab. Students also reported that the experience of successfully living independently in another country in which they did not speak the language made them more confident in general. In one typical response, a NanoJapan alum reported, "The fact that I have had the experience of relocating to a different culture and lab environment and successfully adapting to it means that I have greatly increased comfort and confidence in research environments. After all, relocating to a different lab in the U.S. will always pale in comparison to relocating to a lab on the other side of the world."

- *Training for graduate school:* Several students reported that the NanoJapan experience was important because it provided a first exposure to the science. For example, one alum wrote, "Without realizing it at the time, NanoJapan served as one of the most transformative experiences in my life - the introduction to magnetism and spin-related research that eventually led me to pursue a PhD in magnetics." An even more frequent response was that the experience of conducting research was itself a valuable preparation for the realities of graduate school. An alum explained, "Looking back now, I see that my lab in NanoJapan gave me a realistic taste of graduate school life (the good AND the bad) that many students lack when they apply for graduate school. I know more than a few people that have left their graduate programs because research was not what they expected. Many of these people had performed research during their undergraduate studies as well, which speaks to the accuracy of the NanoJapan experience in particular."

- *Professional network:* The final theme that emerged from these qualitative responses was the importance of building a professional network. Some program alums explained that they were still in contact with their Japanese research hosts. Others described that the NanoJapan program itself provided them with a valuable network of peers interested in science, with whom they could consult about graduate school and career options.

5.0 Impact on STEM Education

In 2008, the NanoJapan Program was awarded an IIE Heiskell Award as a 'Best Practice in Study Abroad' for expanding international opportunities for engineering and science students.[20] In 2013, the NanoJapan Program was included in a National Academy of Engineering report profiling 29 programs that "Infused Real World Experience into Engineering Education". The report highlighted these program as national models for encouraging enhanced richness and relevance of the undergraduate engineering education experience" that would "produce better prepared and more globally competitive graduates".[21] As the program recruits students from universities nationwide, it also serves as a research catalyst for students who may have limited research opportunities at their home universities. This PIRE team continues to enter into new research partnerships to expand our collaborative team, most recently with the Department of Physics at Morehouse College, a historically black university for male students.

The assessment measures used for the program suggest that students perceive that the program enhances their understanding of international research. Perhaps more importantly, we know that the international dimension of the program is a major influence on students' decision to apply to the program in the first place, and thereby get exposure to THz nanotechnology research while early in their academic career. Given that students report the experience of living independently in Japan enhances students' self-confidence, and the independent research project is perceived as a kind of 'training ground' for the realities of graduate school, we suggest that the NanoJapan program has proven to be a successful model for the cultivation of the next generation of U.S. graduate students in the physical sciences.

8.0 References

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