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Undergraduate Research and Study Abroad: Lessons from an NSF Partnership in Research and Education (PIRE) Grant

In this article, we use the results of interviews and post-experience questionnaires with students and study abroad administrators who participated in an NSF-sponsored Partnership in Research and Education (PIRE) grant to explore the benefits and challenges of using undergraduate research as a study abroad experience. Over all, we found that students valued the real learning involved in being a valued partner in an ongoing international scientific endeavor yielding important outcomes. Study abroad coordinators and participating faculty members learned about working with each other in what they described as a cross-cultural experience in its own right. Although some of the outstanding issues of using undergraduate research experiences as study abroad were not fully resolved, we identified several institutional challenges for creating meaningful study abroad experiences for STEM majors.

Undergraduate research and study abroad have gained considerable attention of late as vehicles for promoting experiential learning. Both seek to engage students more actively in the learning process to improve outcomes, and ultimately increase retention and graduation rates (AAC&U; Hu, Scheuch, Schwartz, Gaston-Gayles and Shaoqing 2008). Study abroad has also become important as a means of developing cross-culturally competent graduates who can work in a global society. Over the last few decades colleges and universities have made a concerted effort to increase and broaden the number and diversity of students participating in both undergraduate research and study abroad. Finding study abroad opportunities has been particularly difficult for students in science, technology, engineering, and mathematics (STEM) fields. Although 37 percent of international students who come to the U.S. to study major in STEM fields, only 22.5 percent of U.S. students who studied abroad in 2012-13 were STEM majors This figure includes majors in engineering, physical and life sciences, health professions, and mathematics and computer sciences (IIE 2014).

Despite the fact that the percentage of physical and life-sciences majors studying abroad has risen in recent years, additional efforts have been undertaken in international scientific collaborations to generate even more increases in the number and percentage of STEM majors who study abroad (Blumenthal and Grothus 2009). Undergraduate research would appear to be an effective way to enhance study abroad participation among STEM majors since approximately 40 percent of students in some STEM fields are likely to participate in undergraduate research (Hu et al. 2008).

There is surprisingly little published research on study abroad for STEM majors, and although there is some research on the characteristics of effective undergraduate research experiences, there is little that focuses on marrying study abroad and undergraduate research. Our findings following the PIRE grant lead us to the conclusion that undergraduate research experiences provide a valuable study abroad option for STEM majors. However, since they do not fit the official definition of study abroad for study abroad professionals, they may not be recognized as such. Results from our research provide insight into the characteristics of effective undergraduate research and demonstrate how undergraduate research in an international setting offers the opportunity to achieve outcomes of both types of experiential learning in one combined experience.

Background

In recent years there has been considerable attention to two aspects of participating in study abroad. The first is intention to study abroad and the second is actual participation. Research on the relationship between major and intent to study abroad is mixed. Some studies suggest that major does not have a significant effect on *intent* to study abroad. STEM majors are as likely as those in other fields to indicate they would like to study abroad (Goldstein and Kim 2006; Salisbury, Umbach, Paulsen, and Pascarella 2009). A 2010 study of first-year students at the University of Massachusetts-Amherst found that only engineering majors were significantly less likely to anticipate studying abroad than other majors (Stroud 2010). However, the inclination or aspiration to study abroad seems to diminish over time in college and the drop seems to be greater for majors in the physical and biological sciences (Niehauss 2011). The result is that of the 22.5 percent of STEM majors who actually studied abroad in 2012-13, 8.8 percent were in the physical or life sciences, 4.1 percent were in engineering, and 1.9 percent were math or computer science majors (IIE 2014). Although the data show improvement over thirteen years in the overall percentage of study abroad participants from STEM fields, there is clearly room for improvement in some STEM majors.

Many reasons are given for the reluctance of STEM majors to engage in study abroad. For example, women are much more likely to study abroad than men but make up a smaller percentage of STEM majors. Plans for graduate school also seem to negatively impact plans to study abroad, and STEM majors may be more likely to plan to attend graduate school and thus hesitant to participate in study abroad perhaps for fear it will negatively affect graduate school plans by lengthening time to degree or precluding opportunities to work on research projects with faculty members. Lack of language skills is also another reason given for lower rates of participation by STEM majors in study abroad (Twombly, Salisbury, Tumanut and Klute 2012).

Undoubtedly, a significant reason for the difficulties in encouraging STEM majors to study abroad lies in the structure of the majors themselves. In contrast to the humanities, programs in STEM fields are highly structured, with courses tightly sequenced. Missing a course in a sequence affects progress toward a degree. STEM students may have little room in their full majors to study languages. Research by O'Hara (2009) suggests that science faculty members are less likely than faculty in other disciplines to incorporate international perspectives into their classes or to promote study abroad.

On the other hand, given the nature of STEM fields one might expect undergraduate research to more readily fit with faculty work and the disciplines themselves. The Council on Undergraduate Research defines an undergraduate research experience as one that includes "an inquiry or investigation conducted by an undergraduate that makes an original intellectual or creative contribution to the discipline" (cited in Hu et al. 2008, p. 6). Hu and colleagues note that the nature of research in STEM fields makes it easier to incorporate undergraduates into more progressively complex and responsible roles in research and thus into undergraduate research experiences than in some other disciplines. Early on, students may be technicians filling low-skilled roles, but over time they may become colleagues playing significant roles in all aspects of research (Hu et al. 2008). In fact, by the time they are seniors, STEM majors report at least twice the participation rate in undergraduate research than most other majors (43 percent of physical science majors, 43 percent of biological and life science majors, and 29 percent of engineering majors engage in such research) (Hu et al. 2008). Laboratory-based curricula, accompanied by faculty with large grants and laboratories of their own (at least in research universities), would seemingly make such experiences widely available and attractive.

Research on the outcomes of undergraduate research in STEM fields is surprisingly limited. Examining student-reported gains from undergraduate research supported by grants from the Howard Hughes Medical Institute, Lopatto (2004) found that students noted large gains in the following skills: understanding the research process, readiness for more demanding research, understanding how scientists work on real problems, and learning lab techniques. Moreover, more than half of the Howard Hughes summer research participants in Lopatto's study reported that the experience was better than they expected. Lopatto cites earlier research attributing various outcomes such as college persistence, interest in science careers, and graduate study to undergraduate research. Lopatto's study says little about what made the research experience a successful learning experience for students, though.

Blumenthal and Grothus (2009) report the success of RISE (Research Internships in Science and Engineering) in which American, Canadian, and now British undergraduates conduct summer research internships supervised by German doctoral students at laboratories such as the Max Planck Institute. RISE is sponsored by the German Academic Exchange Service (DAAD) and like the PIRE projects discussed here, offers financial support to allow undergraduates the opportunity to work on serious, supervised projects. Originally focused on engineering, RISE now accepts students in the fields of biology, chemistry, physics, earth sciences, and engineering (DAAD n.d.). Blumenthal and Grothus call RISE an "exciting and attractive program" (p. 23). In particular, RISE seemed to affect participants' interest in world affairs, traveling abroad, and understanding of German professional culture. Over two-thirds of RISE participants anticipated pursuing graduate study and almost half expressed an interest in pursuing graduate study in Germany (Blumenthal and Grothus 2009). However, as a German-sponsored program that seeks to develop German scientific capacity, RISE is not a solution to enhancing U.S. study abroad rates for STEM students.

The NSF grants in the Partnership in Research and Education (PIRE) program are aimed at supporting high-quality projects that advance research and education in ways that could not occur without international collaboration, and thus PIRE seeks to catalyze a higher level of international engagement in the U.S. science and engineering community.

The Pixel PIRE Grant

The PIRE grant was aimed at performing research and development, fabrication, and testing of next-generation silicon pixel detectors to track the particles in subatomic collisions, for the Compact Muon Solenoid (CMS) experiment, at the CERN Large Hadron Collider near Geneva, Switzerland. The CMS collaboration includes more than 3,000 PhD-level physicists from more than 39 countries who operate the detector located at CERN. The international consortium developed with Pixel PIRE, as the NSF grant was known, allowed the participants to create a smaller research consortium within the CMS collaboration to transfer technology from the Swiss partnering institutions to small U.S. research groups. It also provided a framework for cross-generational collaboration among undergraduate and graduate students, postdoctoral researchers, and faculty members. Another goal was to strengthen international exchange programs between the U.S. and Swiss institutions.

The Pixel PIRE grant offered two types of international experiences for undergraduate and graduate students. One was a formal study abroad experience in which participating students could enroll in and receive credit for physics and language courses at the prestigious Eidgenössische Technische Hochschule Zürich (ETHZ), one of the world's leading universities for technology and the natural sciences located in Zurich, Switzerland. Over the course of the grant, nine of the total 26 undergraduate student participants studied at ETHZ for at least one semester. This was a traditional study abroad experience in that it was administered primarily through study abroad offices, and students received academic credit for their work.

All 26 of the undergraduates spent at least two months in an intensive research program with the CMS collaboration. The research was centered at the internationally renowned Paul Scherrer Institute (PSI) located between Zurich and Basel, although some students spent their research time at ETHZ and CERN as well. PSI is known for its work in the natural and engineering sciences and, as such, is a magnet for collaborative research projects. In addition, PSI has a specific goal of training "young specialists and students" (PSI website).

The research experiences for all students were provided within the context of an international laboratory setting, accompanied by many of the cultural characteristics of any study abroad experience, such as travel and visits to local landmarks. However, there were significant differences from a traditional study abroad experience. Students who participated only in the research experience were not enrolled in any course for credit and paid no study abroad fee. As participants in a large grant, students were paid for their research work. Their travel, living expenses, and ETHZ tuition and study abroad fees (for those who enrolled in courses at ETHZ) were covered by the NSF grant.

There is much to be learned from this particular grant with respect to study abroad for science students, as well as for what makes successful undergraduate research experiences. It demonstrates how undergraduate research and study abroad can be mutually reinforcing. These findings are generalizable and scalable.

The Pixel PIRE grant period ran from 2007 through 2013 with a budget of $2.8 million. It involved a collaboration among four U.S. Midwest universities: the University of Kansas, Kansas State University, University of Illinois-Chicago, and University of Nebraska Lincoln, plus the University of Puerto Rico-Mayaguez and the two Swiss institutes noted above, PSI and ETHZ. Although the ultimate goals of the grant were primarily scientific in nature, one of the specific goals was to create a study abroad opportunity involving study, cultural exposure, and research. The core of the student research experience involved carrying out a defined project. The projects emerged from discussions among the PSI staff, U.S. Pixel PIRE faculty, and Pixel PIRE postdoctoral researchers located in Switzerland.

Students worked under the direction of the postdoctoral research associates in close consultation with senior PSI or ETHZ staff members, with oversight from U.S. faculty members. Participating faculty members and students attended a PIRE conference in the fall of each year of the grant at which students presented their work, study abroad representatives and research administrators from participating institutions met, and faculty met to discuss progress on the grant. Conferences on occasion also included specific mentoring activities, such as a lunch to discuss graduate school preparation.

Over the course of the grant 26 undergraduates, 13 graduate students, and four postdoctoral researchers spent at least two months in Switzerland. Each of the five participating U.S. universities, all of which are major research universities, sent at least four undergraduate students and at least three graduate students to participate. As noted earlier, 11 students (nine undergraduate and two graduate) spent at least one semester enrolled at ETHZ (Table 1). Of the student participants, 11 were from traditionally underrepresented minority groups (10 Hispanics and one Native American) and 10 were women. In any single year, there were from nine to 13 student participants in the grant.

The research projects typically involved instrumentation and electronics. There was little differentiation between what was expected for a graduate student and an undergraduate student project. The main difference was how much time the student spent abroad to work on the project, which could have been from two months to a year. An example of a student summer project was one measuring the electric charge collection efficiency of a set of silicon sensors after they had been exposed to radiation. Some of this instrumentation research was published in refereed journals, and the results have been presented at international research conferences. All of the researchers participating in this grant became members of the CMS collaboration and thus took part in the discovery of the Higgs boson, which was announced on July 4, 2012, and for which the 2013 Nobel Prize was awarded to the theorists who predicted it.

One of the key aspects of the Pixel PIRE grant was a vertical-mentoring model consisting of grant faculty and scientists, postdoctoral researchers, graduate students, and undergraduate students. Graduate students were intentionally paired with undergraduate students for peer reviews of talks and papers. The postdoctoral researchers checked daily on the students for whom they were "responsible." The senior faculty members worked closely with the postdoctoral researchers as well as the students. The vertical-mentoring model is based on the principle that by spending time with colleagues who represent all stages of one's potential career, one develops a community and will develop cross-generational as well as international collaborations. For instance, undergraduate students get to find out from graduate students what the real issues are with graduate school as they spend time both inside and outside of the lab together.

Table 1. Description of Student Participants in the Pixel PIRE Summer Research

Participation Category	Number of Participants
Level	
Undergraduate students	26
Graduate students	13
Participating University	
University of Illinois Chicago	10
University of Kansas	10
University of Puerto Rico Mayaguez	8
Kansas State University	6
University of Nebraska Lincoln	5
Gender and Race/Ethnicity	
Female	10
Male	29
Hispanic/Native American	11
Study at ETHZ	
Spent at least one semester at Eidgenössische Technische Hochschule Zürich (ETHZ)	9 undergrads (11 total)

Additionally, postdoctoral researchers get a taste of teaching both undergraduate and graduate students while providing a bridge (at least in this study) between very busy internationally recognized scientists and students.

Pixel PIRE also provided a forum for scientists and study abroad administrators to meet and learn from each other. Study abroad and research administrators from each participating institution attended each of the Pixel PIRE conferences.

Methods and Findings

Data were collected at various points during the grant period with the primary focus being evaluating grant progress for NSF. Post-trip questionnaires were collected from students during several years of the grant (2009, 2010, and 2012) for a total of 22 completed student questionnaires. The questionnaires asked participants to report on a series of experiences covering outcomes associated with the research experience, as well as on traditional study abroad outcomes (see Table 2). The items changed from administration to administration in order to explore themes learned from the prior year's data collection. The post-experience questionnaire also contained an open-ended item asking students to identify five specific skills they learned and the most significant component of the program. Administered toward the end of the grant, the 2012 questionnaire asked somewhat different questions. Due to the small number of participants and the consistency of themes across years, we report only descriptive statistics from the survey.

To probe findings from the post-experience questionnaires in greater depth, focus groups were conducted with students in the fall of 2010 and fall of 2012 at the annual Pixel PIRE conference. Focus-group interviews were also conducted with study abroad representatives, university research administrators, and faculty who attended the 2010 and 2012 Pixel PIRE conferences. Notes were taken and analyzed for themes. The qualitative findings confirmed and extended the survey data. To report the findings most effectively and efficiently, given space limitations, we weave both the qualitative and quantitative findings together in our discussion.

First we report the student outcomes and then we report findings for study abroad administrators. In doing so, we address the following questions:

1. What were the self-reported outcomes for those who participated in the Pixel PIRE program and what program characteristics contributed to these outcomes?

2. How did participating in the Pixel PIRE grant affect study abroad officials' approach to study abroad for science majors?
3. What do perceived program outcomes suggest about the role of study abroad and effective undergraduate research experiences?

As reported in Table 2, the outcomes across the first years of the grant with which students most strongly agreed included: positive relationships with the postdoctoral mentors, development of close friendships, work on their project was a positive learning experience, and appreciation of the opportunity to work with faculty. In the final grant year, student participants strongly agreed that the project was a positive learning experience, that they were able to travel, and that they learned the importance of collaboration. They also agreed that they developed a positive relationship with the postdoctoral mentor and with faculty members and that they had frequent interactions with people from other countries. When asked to identify the single best thing about the program, nearly all of the students named the opportunity to go abroad and work with outstanding faculty and students in an internationally known lab.

These findings are reinforced by the most significant skill gains identified by student participants (Table 3). Student participants were asked to identify up to five specific skills they had developed or improved as a result of participating in Pixel PIRE. The skills fell into four categories: scientific/technical, professional, personal development, and cultural competence. In the scientific category, (computer) programming was the specific skill mentioned most frequently by students across years. In the professional category, gains in communication skills were mentioned most often. Participants reported personal outcomes often associated with study abroad, such as making new connections and new friends, and learning how to adapt to new situations. In the area of cultural knowledge, learning a foreign language and interaction with other cultures were the most frequently reported gains.

These findings were elaborated on in the student focus groups. Students explained that at PSI one has to collaborate because one cannot do the work alone. There were many opportunities to collaborate through e-mail, weekly video conferences, and day-to-day work in the lab. In fact, the students described PSI as a culture unto itself. Being in another culture taught two of them "how lazy I've been all my life" and "what hard work really is." Another student noted, "You will find no one with a case of the Mondays [at PSI]." The PSI daily "mandatory" coffee breaks in which students,

Table 2. Students' Self-Reported Outcomes by Year

Outcome		Mean*	
	2009 (n=7)	2010 (n=8)	2012 (n=6)
Positive relationship with postdoctoral mentors	6.9	6.8	3.3
Developed friendships I want to continue after PIRE	6.4	6.8	
Working on my project was positive learning experience	6.4	6	3.83
Enjoyed participating	6.3	6.4	
Had opportunity to interact closely with faculty	6.1	6	3.5
I understood what my project was about	6	6.3	3.2
Enjoyed working with European students and faculty		6.8	
Learned new skills in particle physics and detector development		6.6	
Developed research collaborations		6	
Learned more about particle physics than would have in the U.S.		5.8	
Learned new technical skills		5.3	
Likely to apply to international graduate school		5.1	
Continue to do work in particle physics		4.5	
Attend graduate school in physics		3.4	
Was able to travel beyond research site			3.5
Frequent interactions with people from other countries			3.3
Learned a lot about Switzerland and its people			3
Learned about collaboration on large science projects			3.5
Would have participated had not been paid for work			2

*Note: The 2009 and 2010 questionnaires used a 7-point scale with 1=strongly disagree and 7=strongly agree; the 2012 instrument used a 4-point scale with 1=strongly disagree and 4=strongly agree.

scientists, and staff came together to talk about everything from science to their projects to traveling in Europe were mentioned frequently as among the most memorable learning forums for students.

In the earlier years of the grant, the study abroad officials involved thought that the students working at PSI were not getting a true study abroad experience because they were stuck in a lab most of the time. The focus-group participants bristled at this characterization. They said that people stereotype them as "lab rats who don't get out much." They described working at PSI as "a normal 8-to-5 job." When they were done with the job, they were on their own. They traveled on their own, went on trips organized by the faculty members, and made Swiss friends. In this sense, their experiences seemed similar to those on any short study abroad program, plus they learned additional skills working in an international setting driven by the norms and culture of a world-class international scientific center.

Pixel PIRE yielded tangible outcomes as well. Of the undergraduates who have since graduated, 10 went on to graduate school and three are employed in industry. Five students obtained their masters degrees and have now gone on to pursue PhD programs at other institutions. Three students have obtained their PhDs and are now in postdoctoral research positions. As noted earlier, many of the students are co-authors on published papers resulting from the grant.

Overall, the most significant outcome of participation as reported in the questionnaires, and strongly reinforced in interviews, was the benefit of international work experience in a collaborative group of internationally recognized scientists. Students felt they were treated as real scientists, and they learned what it was like to be a scientist. They noted that they might have been good physics students before they went to Switzerland but that while there they got real experience and skills. As a result they gained a better idea of what a career in physics would be like. One of the strengths of the Pixel PIRE experience expressed most strongly in the focus groups was that students were trusted partners in the research process, not simply button pushers. Each student identified a real project that contributed in some way to the overall mission and work of the CMS collaboration. Students got to see very tangible results of their work and also had opportunities to present their work to faculty and students at the annual Pixel PIRE conference.

The Pixel PIRE grant implemented a vertical-mentoring model that contributed to and enhanced the research experience. Undergraduate participants worked mostly with a postdoctoral researcher whom they affectionately called "the king of the peons." The postdocs helped students develop their projects and served as the main link between the students and faculty members and PSI researchers whom the students described as very busy. Although most of their daily work interaction was with the postdoctoral researchers and graduate students, undergraduates also developed close relations with faculty participants in the grant—one of the aspects of the grant about which students were very positive. These relationships were evident not only in what the students said but also in how the two groups interacted at the annual Pixel PIRE conferences.

Faculty members were very familiar with students' work, and thus when students made presentations, the level of discourse was conference-like. One of the faculty members commented after hearing the student presentations, "It is hard to remember that you are undergraduate students."

Table 3. Specific Skills Developed Through Participation in Pixel PIRE

Skills*	Number of Students		
	Year		
	2009	2010	2012
Scientific/Technical			
Programming	4	8	2
Technical	4	1	2
Physics	2		
Professional Knowledge/Skills			
Communications skills	3	2	1
Leadership	2		
Networking		2	
Documenting work and presenting it		2	
Personal Development			
New connections/friends	2	4	
Adapting to new situations and environments	1	2	
Specific Study Abroad Skills			
Foreign language	1	4	
Interaction with other cultures/traveling/understanding	2	4	

*Only gains in skills mentioned more than once are included in this table. Fewer students completed the post-experience survey in 2012 than in previous years.

Some students also presented their work at international scientific conferences. Students realized firsthand the international dimension of physics and the importance of international collaboration, and they valued the skills they gained in working across cultures.

Institutional Outcomes for Study Abroad Administrators

As sensible as it may be to combine undergraduate research with study abroad, this study suggests that such integration will not happen without significant changes in thinking on the part of study abroad officials, as well as by scientists. One of the goals of Pixel PIRE was to create an institutional infrastructure to support study abroad in collaborative sciences such as physics. One of the specific goals of the principal investigator was to have study abroad offices recognize non-credit research experiences as study abroad, just as they would the for-credit study at ETHZ. Such recognition would allow students on the research-only experience to be covered by insurance and other institutional services, while not expecting or requiring them to enroll in and pay for academic credits. Having study abroad officials more involved would also ease logistical burdens of study abroad on research faculty.

While student perceptions of the program were consistent across grant years, the focus-group interviews with study abroad administrators revealed fairly significant changes in their perceptions and actions over the period of the grant regarding the efficacy of undergraduate research as a legitimate study abroad experience. In fall of 2010, two years into the grant, study abroad officials had not made much progress in creating institutional structures and processes to facilitate non-credit-bearing research experiences. Their early focus had been overcoming significant problems in organizing the formal study abroad experience at ETHZ. In 2010 study abroad officials were reluctant to acknowledge that the Pixel PIRE summer work experience was actually a study abroad experience, complete with substantial exposure to a foreign culture. They saw such experiences as outside their purview and belonging to academic departments. In their view, students participating in the Pixel PIRE grant should pay study abroad fees and enroll in independent study credits for their efforts as a way of formalizing the work on students' transcripts. In contrast, participating PIRE faculty members were less concerned about records on transcripts than the records on resumes. In 2010, this was a point of some contention between study abroad officials and faculty members involved in the grant.

In the fall of 2012, study abroad administrators were still struggling with some aspects of the infrastructure issues raised by Pixel PIRE, but the tenor and substance of the conversation had changed substantially. Participating institutions had not made progress in creating or accepting non-credit-bearing (thus no cost to the student) study abroad research experiences in the sciences as legitimate study abroad. However, by 2012 there was more pressure on study abroad offices to reach out to the sciences. A renewed emphasis on undergraduate experiential educational experiences, as well as availability of new scholarship monies to promote study abroad in STEM fields, motivated study abroad officials to think differently about how to integrate research experiences such as that offered by Pixel PIRE into science majors' programs of study. For example, one study abroad administrator talked about the importance of taking a curricular-integration approach, locating a study abroad experience (research or otherwise) in a student's program of study that would enhance the educational experience by providing something that students could not get at home. Another talked about examining institutional policies more carefully. In general, study abroad administrators reported learning about how important research experiences are to science majors.

Although external forces motivated some of the change in thinking, change was also a result of persistent and intentional effort by participating faculty members. Participating study abroad officials credited the grant's principal investigator with raising awareness on campus concerning the issues students in STEM fields faced in study abroad and for forcing a conversation about how to facilitate such study. The grant facilitated learning by intentionally creating spaces (the conferences) for study abroad administrators to interact with grant faculty members and students. The study abroad administrators at participating institutions came from the fields that have traditionally been more highly represented among study abroad students: the humanities and social sciences. They reported knowing little about the sciences. One study abroad administrator described learning to work with faculty in the sciences as a cross-cultural experience in and of itself. The gap in knowledge and experience was exacerbated by turnover in study abroad staff. Only two of the five universities' study abroad officials participated for the entire duration of the grant.

As a result of participating in the grant, however, study abroad officials reported coming to realize how important research experiences are in the sciences, and faculty members reported learning more about the logistical challenges of organizing study abroad. Study abroad administrators credited Pixel PIRE with leading them to think more creatively about

Physics students, postdoctoral researchers, and faculty members join research and study abroad administrators at the Pixel PIRE conference with hosts from the University of Puerto Rico-Mayaguez.

research experiences for study abroad. In addition, they came to realize the importance of educating faculty and students about scholarships that actually may favor STEM students in obtaining for-credit, study abroad experience.

Significant challenges remain. For example, scientists (at least at research universities) are accustomed to paying graduate research assistants for work done, and they want to be able to facilitate that for undergraduate researchers as well. Study abroad administrators argued that undergraduates are accustomed to paying for credits, including study abroad, and would do so for undergraduate for-credit research experiences if they were integrated into the major and offered something to the students not available at their home universities. On the other hand, students indicated they likely would not have participated in Pixel PIRE if they had not been paid and had they not had their tuition paid by the grant for study at ETHZ. Had the students been able to take a research experience for credit that was part of their undergraduate major and for which they could get scholarship money, they might have thought differently. At least one participating university's revised general education curriculum might allow an experience such as the Pixel PIRE research (or participation in something like the German RISE program) to count for general education credits. But the faculty would have to submit a proposal showing how the experience met some of the goals of the curriculum. This same university is also working on a project to integrate study abroad into the major.

Conclusions and Implications

Several important conclusions emerged from this study that carry implications for successful undergraduate research, as well as for international research experiences as a vehicle for increasing the number of STEM students who "study" abroad.

Our findings confirm those of Lopatto (2003) about the positive outcomes to be gained from undergraduate research and reinforce those of Blumenthal and Grothus (2009) that undergraduate research conducted abroad yields cultural learning as well. Our findings shed light on characteristics of undergraduate research that make it particularly successful as both a research and study abroad experience.

First and foremost, the undergraduate research/work component of Pixel PIRE was very successful in the eyes of participating students and faculty members, primarily because students were trusted partners in doing real and important work, and they knew it. The CMS collaborators relied on the students' work. Although some of the students described themselves as "grunts and peons," they understood that their small project was a piece of important work being done by the CMS collaboration. The European scientists based at PSI and ETHZ and CERN, as well as the U.S. faculty, recognized the students' contributions as important.

Second, through Pixel PIRE, students gained a colleague-like relationship with participating faculty members and research scientists abroad. The vertical-mentoring model was an important and effective way to get undergraduates involved in faculty members' research and to facilitate meaningful undergraduate research by having a postdoctoral researcher do much of the day-to-day work with students. Students learned first-hand that science is done in research groups with students, postdoctoral researchers, and senior scientists. Student-faculty relationships are at the heart of much of the current research on effective undergraduate education. The vertical-mentoring model promoted such relationships and critically assisted students in their research and the process of learning to be a scientist. Both the seriousness of project and on-site mentorship by a more senior doctoral student were highlighted as strengths of the RISE program (Blumenthal and Grothus 2009).

Third, the students learned how to collaborate with other scientists and the importance of doing so. The nature of the project and the culture of PSI demanded that students collaborate with faculty researchers, with other students, and with their postdoctoral mentors. What made this experience different from a U.S.-based research experience was the fact that students also learned to interact and collaborate with individuals from other countries. They gained programming and other specific skills related to doing physics but also came to understand culturally specific norms and practices. They learned about particle physics, new technical skills, and particle-detector development.

In sum, the Pixel PIRE grant suggests that the impact of undergraduate research experiences is maximized when the experience is authentic, when students are participating in research that is part of an ongoing faculty research agenda and in which student work plays an important part. This happens when faculty members and postdoctoral researchers intentionally mentor student researchers as part of ongoing research. This finding supports previous research and has implications for all STEM undergraduate research whether at home or abroad.

In the case of collaborative physical sciences, the benefits are maximized when that experience is in an international laboratory. The students learn, in the words of one student, "everything that matters." But they also gain traditional study abroad experience such as travel, independence, and familiarity with different cultures and languages. Although students who participate in projects such as RISE also have doctoral mentors, they do not receive the added benefit of working on their own professors' research and of developing close relationships with them that persist on the home campus. These relationships are important for the future careers of the students and for the faculty members as the students progress to graduate school or to industry.

Institutional Challenges and Implications

The international nature of the sciences demands that researchers be able to operate across cultures, collaborate, and develop a global competency. For this reason, international research experiences for undergraduate physical science majors are critical for their training. Experiences such as the Pixel PIRE provide an opportunity for students to learn these skills without participating in a traditional course-based study abroad program. However, this study points to some institutional obstacles that must be overcome to aid scientists in promoting research abroad for undergraduates.

First, institutions must find ways to recognize undergraduate research as legitimate study abroad without it necessarily being tied to credit-bearing courses. This study suggests that both scientists and study abroad professionals must aggressively work to bridge a gap in understanding between the two groups in this project. Both groups admitted to being unfamiliar with the interests and needs of the other. Although time spent together during the grant increased mutual understanding, faculty members and study abroad administrators have somewhat competing interests that are not easily overcome. Study abroad professionals need to get students into (and to pay for) study abroad programs to make their operation financially viable and to receive credit for the number of students they send abroad each year. Meanwhile the Pixel PIRE faculty participants were more concerned about providing an enriching work/research experience for students that would help them in their careers. As long as study abroad is self-supporting, it is unlikely they can or should offer services at no cost to students (e.g., no study abroad fee).

This argues for finding ways to integrate undergraduate research abroad into majors or into general education requirements for which students might be willing to pay, especially given the benefits. Availability of scholarship funds would also make paying for an undergraduate research experience abroad more palatable. Short of scholarship funds, even small grants could subsidize the study abroad fee, allowing students to have insurance, for example. Finding ways to pay for such experiences is only part of the challenge. Involving undergraduates in authentic, international, faculty-driven research abroad is perhaps easier to accomplish at research universities than it may be at smaller institutions. Project RISE provides one model by accepting students from any institution and providing the postdoctoral mentors for the students. The limitation of Project RISE is its capacity; it is small and not limited to U.S. college students.

External funding agencies such as NSF could encourage grants that involve not only a vertical-mentoring model but that also encourage involvement of different types of institutions. The concept of vertical mentoring could be adapted depending on institutional type with seniors mentoring freshmen, for example, or master's students mentoring undergraduates. The Pixel PIRE model also suggests that alternative approaches involving institutional collaborations may encourage more women and students from underrepresented groups to major in STEM fields. Over the course of the grant, Pixel PIRE included 10 women and 11 Hispanic or Native American students out of a total of 39, and by all accounts was successful in attracting a diverse group of participants.

The issue of what should count for study abroad in the sciences was not resolved by this particular grant, but the Pixel PIRE experience raises important general issues for how global scientific competency can be gained. Most significantly, this study echoes Bluementhal and Grothus (2009) by suggesting that if the scientific community, universities, undergraduate research programs, and study abroad professionals wish to increase the number of STEM majors with an international perspective (and not just add to institutional study abroad numbers), multiple models may be necessary, including non-credit undergraduate research experiences. The study abroad administrators involved in Pixel PIRE were not totally convinced of this, but as models of integrating study abroad into majors and alternative definitions of what counts as study abroad gain credence, even those views are changing. Michigan State University, for example, encourages research experiences abroad and dedicates a web page to providing useful links for interested students (MSU n.d.).

Final Comments

This study suggests that undergraduate research abroad can accomplish simultaneously the goals of building research skills as well as cross-cultural skills. Such experiences will be particularly effective to the extent they are based on ongoing faculty research, allow students to work on real projects that play a role in that research, are supported by faculty members as well as postdoctoral researchers (or in the case of smaller institutions, more-advanced students) and have an international dimension that brings together researchers from various countries and cultures to solve real scientific problems in the collaborative methods of science. However, the research also suggests that, short of grant funding, these experiences will be difficult to institutionalize unless colleges and universities build them into the regular curricular structure and count them as legitimate study abroad.

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