# THE ROBERT F. KENNEDY SCIENCE RESEARCH INSTITUTE

Bonnie A.B. Blackwell — Department of Chemistry, Williams College, Williamstown, MA 01267, bonnie.a.b.blackwell@williams.edu

Joel I.B. Blickstein — RFK Research Institute, Flushing, NY 11366

Mimi N. Divjak — RFK Research Institute, Flushing, NY 11366, k9bqc@hotmail.com

Anne R. Skinner — Department of Chemistry, Williams College, Williamstown, MA 01267, anne.r.skinner@williams.edu

## ABSTRACT

By performing multidisciplinary hands-on science research, 6-10 high school students each year develop their critical thinking, logical reasoning, scientific writing and presentation skills. Supervised by Williams College Electron Spin Resonance (ESR) Lab staff, students prepare teeth and other fossils from archaeological and paleontological sites for ESR dating. They are involved in the all aspects of the research, except those directly involving radiation, from selecting and preparing the fossil samples for dating, to running the Williams ESR spectrometer, and calculating ages. Mentored by the scientists, students prepare detailed reports to publish in scientific journals and present their data at scientific conferences, science fairs, and to science classes in their home schools.

Keywords: education, undergraduate, highschool, science research.

## INTRODUCTION

Few American students want to become scientists or engineers, instead wanting to follow medical or business careers (Howard Hughes Medical Institute, 1997). The reasons are many and varied, but in part, stem from their extremely limited experience with real scientific work. Some students, however, will change their chosen profession after having experienced a science research project. For some NYC high school students, the current curriculum offers few challenges, but entrance to top flight colleges requires them to have something special on their résumés to set them apart from the crowd (Steinberg, 2002). Consequently, many NYC high schools offer advanced courses in research methods and try to place students in real laboratories for research experiences.

By experiencing scientific research, students become excited about science (Maurer, 2000), especially when they take possession of their own projects. Students get a realistic hands-on understanding about research. Archaeology and paleontology are two topics that particularly attract students (Brown, 2000). Although fieldwork can “turn on” people to paleontology and archaeology more effectively than many other activities, students cannot visit their “own” sites, because of the costs and logistics involved. The RFK Science Research Institute trains NYC high school students to perform university-level hands-on scientific research that helps to develop their critical thinking, logical reasoning, creative scientific writing, and presentation skills, thereby improving their long-term educational performance. Students, teachers, and scientists work cooperatively as a team, but each student participant has their “own” individualized project to complete.

Since 1994, we have taught 49 high school students to perform ESR dating (see Table 1). The program was started to enable Queens students from public high schools that cater to an academically mixed or underserved population (as opposed to those that cater to only academically advanced students) to participate in scientific research. ESR dating is particularly suited to high school student research, because they can, with relatively little training, learn to become skilled sample preparators and analysts. Since many Queens high school students come from immigrant families who cannot, or do not, wish to let their children, especially females, be absent from home for prolonged periods, these students do not get to join expensive summer internship programs based far from home (Roser, 1995). In summer 2000, we expanded the program’s size from the usual 3-4 students per year to 10 students, thanks to a Toyota Tapestry grant. In 2001, nine were enrolled in the program.

From 1994 to 1998, we ran the research program from labs at Queens College. When that location was no longer available to us, we formed the RFK Research Institute to continue to offer NYC high school students the opportunity to do research projects with us. The high school student research program fulfills a real need for our lab, because ESR dating requires long hours, sometimes more than 150, of manual sample preparation for each tooth that is dated (Blackwell, 2001). Since part-time technicians are hard to find at Williams College, we desperately need people who can devote a month or two to preparing teeth for us each year. Since 1999, the institute lab has processed 103 teeth, most with multiple subsamples, plus other fossils, for approximately 320 independent ESR analyses. This is 50% more than the output from the main lab at Williams in the same period.

To maintain access for NYC students, we created satellite ESR preparation lab facilities at Robert F. Kennedy High School (RFK) and Townsend Harris High Schools (THHS) in Queens where students prepare ESR dating samples. Scientists (JIBB, BABB, ARS) and technical staff (MND plus undergraduates with experience in ESR) from the Williams College ESR Dating Lab supervise the operation to enable 6-10 students per year to perform scientific research, while living at home for most of the summer. For 10-14 days,

| Students | White | | African-American | | Asian[1] | | Hispanic | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| | F | M | F | M | F | M | F | M | F | M |
| High School | 12 | 3 | [2]3 | 3 | 13 | 8 | 5 | 2 | 33 | 16 |
| Under-graduate | 14 | 7 | 2 | 7 | 6 | 4 | 1 | 1 | 23 | 19 |
| Graduate | 2 | 2 | 0 | 0 | 0 | 0 | 1 | 0 | 3 | 2 |
| Total | 28 | 12 | 5 | 10 | 19 | 12 | 7 | 3 | 59 | 37 |
| % | 29 | 13 | 5 | 10 | 20 | 13 | 7 | 3 | 61 | 39 |

**Table 1. Student participation in the ESR research program (1994-2002). Notes: 1, includes East Indians, 2, includes one student who was also physically challenged.**

they work at Williams College to do the ESR spectrometry.

## THE RFK SCIENCE RESEARCH INSTITUTE IN ESR DATING

This program runs on the principle that the students work on every phase of the research that safety guidelines will permit, while they are in constant contact with at least one and often two or three ESR scientists, and one to three technicians. All students work cooperatively as part of the team to complete the research, yet each is responsible for all the analysis for “their” site. Some of the technicians we employ have been through the research program as students themselves, which helps them to mentor other students under their supervision. Three current and six previous ESR technicians began as high school students in similar research projects.

Unlike some projects that can frustrate first-time student researchers by not giving positive results, the dating projects will produce valid ages > 95% of the time, provided the students work rigorously. Since the scientists oversee every step, student success is virtually guaranteed. When the students write their reports and projects, the scientists are there working one-on-one to help the students comprehend all aspects of their accomplishments. Such personal mentoring by the scientists significantly raises the students’ understanding about their projects and helps to guide them through the academic choices that they must make for college applications and course selection.

While the majority of the high school student research has involved determining ESR dates for various sites (e.g., Blackwell et al., 1996), a few students have done developmental projects, such as developing new ESR dating protocols for new materials (e.g., Blackwell et al., 2002), or examining geochemical trace elements to develop environmental guidelines for fossilization processes. These projects provide more of a challenge to the scientific staff to ensure that something positive can be achieved by the student in the time available. Projects which are too open-ended in their goals do not raise enthusiasm with the high school students and they will abandon the project, unlike graduate students who will often stay with such work despite numerous frustrations. Consequently, we have tried few developmental projects with the high school students, after two early attempts in which students ended their research without positive results. Recently, however, we have found that very focused projects can work if the student is really dedicated. For example, one student worked two years to test the suitability of dentine for ESR dating (Blackwell et al., 2002). In that project, the student and our staff set very specific goals at the outset. Although the student was aware the project might not succeed, we ensured that they would have some positive outcome by first running some very preliminary tests ourselves. Then, the student expanded the number of samples tested and improved the protocol. Because he was taking a protocol which we knew worked well enough to give some positive results, any improvements he made were bonuses. The reduced stress that this placed on the student also helped to ensure the project’s success. We have since repeated this formula successfully with another three students. In case the developmental projects did not work, these students also worked on mammal teeth also (e.g., Paddayya et al., 2002).

We recruit high school freshmen, sophomore, or junior students from non-elite schools to join the institute. We target particularly schools with high numbers of minority students, such as Springfield Gardens and Franklin K. Lane High Schools, > 90% of whose students are African American or Hispanic, or RFK High School, whose students speak 78 different first languages. These are schools in which students have few, if any, opportunities to do research programs, take AP classes, take free credits at the local colleges in place of school classes, or see a real research lab. Schools receive information on the program in early January. Students must submit a detailed questionnaire to demonstrate their interest in science generally. After reviewing the submissions, each viable candidate is personally interviewed by at least three of the staff, including a former student, to be sure that they will fit and work effectively with the group. We strongly encourage sophomore and junior candidates who complete a year with us to return for a second year.

The initial safety training uses mock situations, a method developed and tested by one of our students. Then, experienced ESR scientists introduce students and teachers to ESR dating through a 12 hour lecture series and by having them read scientific papers on the theoretical physics, chemistry, geology, paleontology, and archaeology underlying the technique. Students are asked to write reports synthesizing this material almost immediately.

Scientific and technical staff train participants to prepare samples for dating. Each student selects a different site, based upon their particular interests, from among paleontological, hominid, and archaeological sites from which samples have been submitted to the lab for dating. Each prepares a plan for dating the site, which involves doing a detailed literature search using Science Citations Index and other indexing programs to find articles pertinent to their topics, examining the field notes from sample collections and the teeth available for dating. Students work for 30-32 hours per week over 8-9 weeks in the summer, mostly in the satellite preparation lab to prepare their samples. During 10-14 days in August at Williams College, they learn to operate the ESR spectrometer and analyze their samples under the supervision of the scientific staff.

Under the guidance of ESR dating scientists and teachers who have researched with us, students prepare reports for entry into local science fairs, and make presentations to their fellow students. At the end of the summer, students are expected to produce a report approximately 20 pages in length detailing the theory behind ESR, the archaeology/paleontology of their site, their results and conclusions. Every one-two days, they submit a small segment of that report, which is returned with feedback within a day. After the Williams visit, students return to NYC to calculate their ages and write their final reports. By the time that they finish the summer, they may have revised the work 10-20 times.

Each student is expected to do at least one and usually two to three presentations about their project over the summer. We share the high school building with a math-science enrichment program. During their research time, each student presents a summary of their project to the middle school students and teachers in the Math-Science Institute at THHS to teach them about the basics of ESR dating and Quaternary geology/archaeology in general. They also make one or two presentations to their peers in the research class about their own projects.

The program continues in the fall and winter as students continue to write their results for science research credits. Some take this as a regular school credit for an additional science research credit. This allows us to continue to work with students to understand the results that they have achieved. Data from some analytical procedures, which are contracted out to other labs, are received over the fall. Guided by the ESR scientists, with help from the site paleontologists or archaeologists, students prepare an abstract for a scientific conference and a scientific paper for publication. Many also update their summer's research report as Intel and/or Siemens-Westinghouse projects. All also prepare a science fair project for the local science fairs. This involves preparing a poster, speech, and for some fairs, a powerpoint slide presentation.

Should students continue in the program for more than one year, they assist in training other students. Throughout the learning process, students work in teams on all aspects of the project. They receive training to build critical friends' peer coaching groups that we know continue long after the students leave the research institute. The work requires a detailed understanding of mathematics, physical and biological sciences, and the ability to work as an integral scientific team member. Working one-on-one with lab scientists and technicians, students perform all the steps for ESR dating, except for those steps in the protocol involving irradiation.

ESR dating research teaches students about the rigors of scientific research and the excitement of research on the cutting edge of science, providing the sense of achievement that can only come from doing their own projects. The research integrates physics, chemistry, archaeology, paleontology, geomorphology, mathematics, and computer science skills with scientific literacy, presentation skills, and the planning necessary to complete a research project. Students can develop a life-long interest in scientific research, archaeology, and paleontology. Their experience will have an impact on their career choices. For example, Salem Fevrier wanted to be a doctor, but this past summer he participated in an intern program at Wood's Hole Oceanographic Institute. This would not have been possible for him had he not worked in our program and received a scholarship to Williams as a result. Helen Leung wanted to study business when she joined our program. Since then, she has taken several archaeology, paleontology, and geology courses at Barnard where she is currently a senior in chemistry. She has now worked as a lab technician in two other scientific research labs in addition to ours. Tina Sani, thanks to her participation in our program and her success in the Westinghouse contest, attends Cooper Union University, where she will take a graduate program next fall in computer engineering. Steve Berman, was also toying with medicine as a career, but is now studying molecular biology in Cornell's agricultural faculty. He continues to research with ESR and this summer returned to work with our program as a staff member.

## RFK ESR LABORATORY FACILITIES

Housed in either the RFK or THHS science lab complex, the ESR satellite lab facilities contain all the equipment needed to prepare samples for ESR analyses up to the irradiation step, including drilling stations, powdering and grinding equipment, fume hoods for cleaning and reagent preparation, research-calibre balances, micrometers for sample thickness determinations, and assorted smaller equipment. Blickstein and Divjak are both qualified NYC high school teachers, who also hold NYC Fire Department safety certificates for laboratory management. Both, however, are experienced ESR

| Publications | Papers | Abstracts | Total |
|---|---|---|---|
| Has high school students as authors (some more than one) | 6 | 30 | 36 |
| Has a high school student as first author[1] | 1 | 11 | 12 |
| Was presented by a highschool student at a conference[1] | - | 2 | 2 |
| Includes >50% of data produced by high school students but no student authors | 9 | 10 | 19 |
| Total | 12 | 39 | 55 |

**Table 2. High school students' published research (1994-2002). Notes: 1, included in count for papers with high school authors.**

scientists with significant backgrounds in geochemistry. As such, they provide a vital link acting as both teachers and scientists.

## MEASURING STUDENTS' SUCCESS

Throughout the project, students receive constant feedback on their preparation skills and writing from the staff. At the weekly lab meeting, the group can discuss their experience, brainstorm solutions to any problems, and modify the training program, if needed. Although the scientists can gauge their understanding fully when students have presented a report that fully documents their project, including ESR theory, methodology, results, and conclusions, students are asked to write smaller sections of the report on a daily basis, allowing us to pinpoint some problems in understanding very early.

In the summer, the students receive a science research credit. The grade for that course is determined by assessing the quality of the results produced, the written work submitted, and their presentations to their peers and other school groups. Generally, we expect work of potentially publishable quality. Their reports should be able to be submitted to our archaeological/ paleontological collaborators with little or no polishing. Their abstracts should require little alteration before being submitted to national or international conferences for presentation (e.g., Blackwell et al., 1996, 2001c; Table 2). Similarly, the papers should require relatively little extra work to become a publishable paper, although here, the work from several students may need to be combined to provide a sufficiently complete paper for publication in an archaeological or paleontological journal or monograph (e.g., Lau et al., 1997; Blackwell & Skinner, 1999; Blackwell et al., 2000; Table 2).

Although we discuss their success individually with each student many times over the program, the most detailed evaluation occurs when the ESR spectroscopy has been completed. At the end of the summer, the quality of their research is judged on several criteria, such as:

1. Are the spectra clean with no interference?
2. Do the samples give good accumulated dose growth curves?
3. Are the data records suitable that someone else can understand them?
4. Have they completed a reasonable number of analyses given the difficulty of their samples to prepare?

In the summer, the students are graded on their report. Because it is a work in progress, we are more concerned that we see improvement constantly rather than just seeing a "finished" product. One problem we have is in trying to improve the students' scientific writing from typical NYC high school student level to one suitable for writing the scholarly scientific abstract and paper. While this may seem an excessively high goal, the nature of the method, being very interdisciplinary and technologically complex, requires high reading and writing standards in order to be certain that the students truly understand the concepts well. We also often have the added problem of poor English, because many students come from newly arrived, or first generation, immigrant families, where English is not their first or, in some cases, their second language. Criteria, therefore, tend to be flexible for the summer segment:

1. Do they understand from their written work the theory behind ESR dating, along with some Quaternary geology and archaeology specific to their project?
2. Do they understand how to find and properly cite references?
3. Does their report include all the data necessary to form the basis for a real scientific paper on their project?
4. Is the writing clear enough for us to understand their meaning?

In their presentations to other classes, students are expected to:

1. Clearly present the theory at a level appropriate to the class or audience that they are addressing.
2. Explain the significance of the work that they are doing, both archaeologically/paleontologically and for the general public (i.e., why their relatives should be interested in what they are doing).
3. Prepare clear visual aids to supplement their presentation suitable for the group they are addressing.
4. Be prepared to answer questions on their presentation at a suitable level for the group they are addressing.

In the fall and winter, the grade for students is more rigorously determined, primarily from the quality of the dates produced, the quality of the written work they submit, and their presentations to other school groups. Submitting a project to a science competition or presenting a project at a science fair provides a second measure of their success. When abstracts containing the students' research are accepted for presentation at scientific conferences, we know that they have produced university-calibre research (e.g. Blackwell et al., 2001c, 2002). Finally, publishing papers containing their work with the students as co-authors documents the scientific quality of their work (e.g., Blackwell et al., 2001a. These measures of success all involve some form of peer review. Science fair judging teams in NYC usually include at least one professional scientist, although rarely a geologist. Conference reviews vary in their criteria, but journal and monograph articles receive close scrutiny by geologists and geoarchaeologists.

During fall and winter, the quality of their research is judged on several criteria. For the ESR dating projects, we use criteria such as:

1. Are the data complete? If not, do they understand what needs to be done still? Can they recommend further analyses?
2. Are the uncertainties on the data typical of a good ESR date?
3. Have they completed a reasonable number of statistical tests to determine the robustness of their results? Have they examined potential sources of systematic and random errors? Do they understand the underlying assumptions that enable the calculations?
4. Are the results consistent with archaeological, paleontological, and geological criteria for the teeth dated? If not, can the student explain the discrepancies and suggest possible experiments to test these hypotheses?

In other words, is the work publishable?

Assuming that the work is publishable, and we try hard to ensure that this will be the case by constant supervision throughout their research experience, we expect them to prepare written work to contribute to those scientific publications. Usually, they are expected to prepare a scientific abstract and an updated report that will be the basis of the scientific article. For some good writers, we ask them to write the scientific paper, but usually it still needs work to make it suitable for publication. This work is graded based on several criteria:

1. Does the scientific abstract or report include all the details typically included?
2. Is the writing scientifically concise and precise?
3. Have they prepared suitable tables and diagrams to illustrate their work?
4. Have they produced a publishable work? If not, how much do we have to do to make it so?

Their winter presentations usually include presenting their science fair posters and talks to other school groups and at the science fair. Two of our students, however, have presented their work at the Geological Society of American annual meeting. In their winter presentations, students are expected to meet the same criteria as before, but now the bar is higher because the audience includes the scientists who judge the science fairs, while the visual aids need to be at a level expected for national or international conferences.

## DOES THE PROGRAM SUCCEED?

Among the 49 students trained since 1994 (Table 3), only four did not complete the program. Most continue to work with us for at least one more school year, and some for several years. A number have returned as technical staff in summers after they graduate high school. Others continue to drop into the satellite lab to offer help to current students with projects or to see what work is ongoing. Most "graduates" continue to remain in touch as they continue their careers.

This is not to say that we have not had a few problems in dealing with students or parents. Several times, students have had to bring young siblings whom they were babysitting along to the lab. In one instance, where this became a regular practice, we had to consult the parents. When they could not be convinced that the lab was not an appropriate place for several young children, and that their daughter would benefit more from training with us than babysitting, she was asked to leave the program. Two others were asked to leave when they failed to live up to commitments to their school's research program requirements.

Reasons for not continuing have been varied. One student moved, while another developed severe health problems and withdrew. Several who completed the summer decided they did not have the time to commit to the fall/winter program due to the demands of school. Some juniors who did not return for the second summer went to other research programs, where they did stellar work.

We have had to make some interesting adjustments to handle cultural/religious/family issues. For example, one young Afghani woman would not have been allowed to travel to Williams, if we had not also allowed her mother to accompany her, despite the fact that we already had three female supervisory staff. Even then, the woman's mother was severely criticized by other relatives for such liberal practices. For two students, we had to make arrangements for long-distance lectures and paper submission, while they visited a sick parent or grandparent. For another student was refused permission to visit Williams after she had started the program, we arranged for other students and staff to do her ESR analysis, in order to provide her with the data to write the papers. We have had to arrange a variety of special diets from Hillal and kosher to vegan and Hindi. Given the cultural mix of students, we have had no problems with students not working well together, probably thanks to our careful applicant screening. We also act as guidance counsellors with respect to college applications, highschool course selection, college course selections, and even sometimes on personal issues. We all write numerous reference letters for their undergraduate, graduate school, scholarship, internship, and job applications.

Every student who has completed a project so far has obtained valid, publishable results from ESR dating teeth. At more than local 80 science fairs and competitions, every entrant has won some prize. Five students have been national semi-finalists in the Intel or

| Longevity | Sophmores | Juniors | Seniors | Total | (%) |
|---|---|---|---|---|---|
| High school students enrolled | 3 | 16 | 33 | 49 | 100 |
| Asked to leave the program | 0 | 3 | 0 | 3 | 6 |
| Did not complete the first summer[1] | 0 | 3 | 1 | 4 | 8 |
| Returned for one or more fall/winter sessions | 2 | 8 | 25 | 35 | 71 |
| Returned for a second summer as a student | 2 | 7 | - | 9 | 53 |
| Returned for a third summer as a student | 2 | - | - | 2 | 67 |
| Currently in the program | 1 | 2 | 4 | 7 | 14 |
| Doing collaborative research as a college student | 0 | 3 | 6 | 9 | 18 |
| Worked as technicians/trainers | 1 | 3 | 5 | 9 | 18 |

**Table 3. Student longevity in the program. Notes: 1, includes those asked to leave.**

Westinghouse competitions, while one placed in the top ten in the NY State Westinghouse competition. Another, from arguably the worst school academically in Queens, attended the International Science and Engineering Fair with his project as a NYC representative where he won several awards. These results suggest that the students' understanding is sufficient to convince other scientists that they are doing excellent work

As of August, 2002, 39 abstracts and 12 journal articles based on the students' work (see reference list & Table 2) have been submitted or published. If publishability is a suitable criterion for the quality of the student research, then many students have produced high calibre work. Some work has been profiled in the popular press, such as that by Lau (Lau et al., 1997) which received and continues to receive international attention from many newspapers and magazines.

The impact, however, extends beyond the annual student participants. Led by the student participants, the lab provides scheduled tours for junior high school students involved in the THHS Math-Science Institute, which highlight the scientific basis for the research, allowing other interested teachers and students to observe the work in progress. Students present their results in seminars to local science classes, and local science fairs. Thus, many students, teachers, and parents learn about the science performed at RFK.

Finally, we might want to ask if the program is encouraging more students to become science researchers. While we try to monitor all our students' progress through their university careers, measuring if the program has changed their career path is not easy: Few students graduating from college take the career path that they would have selected to follow when asked while in high school. Granted that our students must express some interest in science initially to consider joining the program. Many, however, have come in stating that they wanted to be doctors and surgeons, while a sizeable number have planned a career in business while still in high school. Of the program "graduates" who have completed university, two who wanted to be surgeons while high school students now work as medical researchers, two other would-be surgeons are now studying science in graduate school, while three others who planned business careers while in high school are working in technological careers and one is a science teacher. Of those still in university, > 75% are taking science or engineering programs. Eight would-be business majors are now enrolled in science or engineering programs, and one in archaeology, while a would-be surgeon now studies agricultural science and a would-be physical education major studies chemistry. Only one would-be business major has remained in a business program.

Nevertheless, the students' attitudes about, and knowledge of, science change drastically. Student knowledge is surveyed when they enter the program and at the end of the summer with a questionnaire, in which they detail their expectations and show their science knowledge. After the summer program ends, they evaluate their summer experience and complete a similar questionnaire. We use these comments to improve the program for the following years.

Comparing their initial and final performances on the science knowledge section of the questionnaires clearly demonstrates that students have developed a fuller understanding about science research, especially geochronology, early hominid paleontology, vertebrate paleontology, Paleolithic archaeology, and Quaternary studies, while experiencing the process in which a project moves from the research problem's description and planning, through the lab work and calculations, to publishing the results. On average, their ability to correctly answer specific questions, such as "describe Quaternary climates" or "explain how hominid populations interacted in Europe at 35 ka", increased by more than 50%. For more general questions, such as "explain how humans evolved over the last 5 million years" or "explain how geologists can identify the relative age of rock layers", their ability to write significantly more detail in their answers increased by 100 to 400% on average. Their understanding about, and application of, scientific concepts, such as experimental uncertainty, statistical significance, the scientific method, and hypothesis testing, increased by more than 80%.

We know that attitudes have changed, because we constantly here comments like "I never knew you had to do so much work to produce a paper!" or read comments like "I had no idea how much finicky work was needed to complete an analysis before I started the program" on the surveys at the program end. Their parents often echo these sentiments. The problem in judging the effectiveness of the program specifically comes in separating its effect from the normal maturing process that would occur without the program. One statistic shouts that the students enjoy their experience and are energized by it: 53% of juniors return for another year of research with us, while 18% have come back to be technicians and another 18% have continued to do research with us in some capacity after entering university. On average, once a week we have an email from a former students asking how the program is going this year, what the students have accomplished, and where we are doing research now.

In the final program surveys, > 95% of students have said that they had fun and would recommend the program to a friend. We have had requests from friends and relatives of several students to join the program, because they heard good things from the students in the program. One student wrote this year from Pennsylvania begging to join the program.

We plan to implement a more formal evaluation system, but lack of staff resources have made this a lower priority than working with the students to ensure their success.

## GEOARCHAEOLOGICAL, PALEONTOLOGICAL, AND GEOCHRONOLOGICAL IMPLICATIONS

Not only does this program provide a valuable educational experience for high school students, it provides absolute dates for sites with important hominid, paleontological, and cultural remains. Even if the students leave the program before completing abstracts, we still use their data. As we understand their ages, especially for those from critical paleontological and archaeological sites, like Olduvai Gorge (Skinner et al., 2003), Gladysvale, Tsagaan Agui (Blackwell and Skinner, 1999), Divje Babe I (Lau et al., 1997), Isampur (Blackwell et al., 2001c; Paddayya et al., 2002), Makapansgat Limeworks (Blackwell et al., 2001d), Mezmaiskaya, Matuzka, and Treugol'naya (Mass et al., 2002), their importance in the larger picture of hominid biological and cultural evolution becomes evident.

The developmental projects have broadened the scope of our research. For example, we are now actively investigating using mammalian dentine and shark enamel for ESR dating, thanks to the high school students. Having large numbers of samples processed provides large databases for intra- and intersite variability comparisons (e.g., Blackwell & Blickstein, 2000; Blackwell & Schwarcz, 1996; Blackwell et al., 2001b), that improve our understanding about fossil diagenesis, sedimentary dose rate variations, and many other geochemical phenomena important to ESR dating, other Quaternary geochronological methods, and geological sciences in general.

Because the dates also make possible detailed time-stratigraphic environmental analyses, the students data help us to understand paleoclimatic change during the Quaternary and late Pliocene, as well as human and mammalian evolutionary response to climate change. Understanding paleoenvironments is critical in modelling species response to environmental change, as well as serving for a proxy for modern climate, vegetational, and faunal changes. Environmental change in central Europe, Asia, India, and southern Africa during the late Pliocene to Middle Pleistocene, from which many of the samples come, is very poorly understood, often because most sites are poorly dated. For example, the work by the students Bev Lau, Helen Leung, Edwin Yu, and Shuwei Yin at Divje Babe I have allowed us to make some extremely detailed paleoclimatic reconstructions for the Slovenian Alps between 120 and 40 ka (Turk et al., 2001; 2002). Such work pushes the frontiers of science long after the students cease to be involved directly.

## EDUCATIONAL IMPLICATIONS

During the past eight years, the ESR dating program has enjoyed help from numerous students, many of them high school students. ESR dating itself has proven particularly attractive, because it offers a 95% guarantee that students will achieve successful results from their efforts. Several of our "graduates" are still enrolled in university, several in science (e.g., Salem Fevrier, Williams College; Donovan Chaderton, Brown University; Natalie Rosenwasser, SUNY Binghamton; Steve Berman, Cornell; Tanya Lopez, Florida U.; James Latopoloski, Queens College Honor College, CUNY; Andrew Condiles, Hobart & William Smith Colleges; Helen Leung, Barnard College, Columbia U.), and engineering (e.g., Tina Sani, Cooper Union U.; Edwin Yu and Tony Mei, Polytechnic U.; Hoang Dang, Stevens Institute of Technology) programs. While all these students would likely have entered university and graduated even without having experienced our program because all were B students at a minimum, their careers have been enhanced by having published papers or abstracts. Undoubtedly, it contributes to students' being accepted to top flight schools to have published abstracts while still in high school (e.g., Condiles with three abstracts by his senior year; Chaderton, Latopolski, Leung, and Lopez with two each; Berman, Sani, Lopez, Lau, Chen, Patel, Mei, etc., with one each before high school graduation). With a B average in Grade 11, it is unlikely Condiles would have gotten the sizeable scholarship he did. Fevrier would not likely have received full scholarship to Williams without having been in the program, nor Chaderton a full scholarship to Brown had he not done so well in his research. Bev Lau, Megan Dwyer, and Natalie Rosenwasser all have published an article in a scientific journal before completing their university programs, Helen Leung had two in print by her third year. Salem Fevrier published one within a week of starting his second year, and Donovan Chaderton within a week of starting his first year at university. Natalie Rosenwasser should have one in print before she finishes her second year, and Sergey Mass before his first ends. This should make them more readily accepted to graduate schools should they choose to apply.

The students also help to educate others around them about their projects, including their parents, teachers, and other students, all of which helps with general science education. At student science fairs and seminars in class, the RFK program participants reach many other students to encourage them that science is fun and interesting. This is particularly true when they visit the middle school students in the Math-Science Institute.

With scientific projects ideally suited to high school student research, the RFK Science Research Institute provides a valuable service to the scientific community and for its students. The program includes a high percentage of minor and underrepresented groups helping them toward scientific and engineering careers. Although labour-intensive for the scientists, its benefits far outweigh its minor problems.

## ACKNOWLEDGEMENTS

Research profiled here has been supported by grants from the Toyota Tapestry Foundation, National Science Foundation (SBR 9709912, 9896289, 9904376), Leakey Foundation, CUNY Research Foundation, Williams College, National Geographic Society, and the Howard Hughes Research Foundation programs. We thank the NYC Board of Education for their continuing cooperation and assistance with this program.

## REFERENCES

Blackwell, B.A.B., 2001 Electron spin resonance (ESR) dating in lacustrine environments. In W.M. Last, J.P. Smol, eds. Tracking Environmental Change using Lake Sediments: Basin Analysis, Coring, and Chronological Techniques, vol. 1. Kleuwer, Dordecht, p. 283-368.

Blackwell, B.A.B., Blickstein, J.I.B., 2000, Considering sedimentary U uptake in external dose rates determinations for ESR and luminescent dating, Quaternary International v. 68, p. 329-343.

Blackwell, B.A., Schwarcz, H.P., 1996, How accurately do modern external dose rates reflect paleodose rates? LED 96, 8th International Conference on Luminiscence and Electron Spin Resonance Dating, Canberra.

Blackwell, B.A.B., Skinner, A.F.R., 1999, Assessing results from conventional ESR (electron spin resonance) dating: Subalyuk, Hungary, vs. Tsagaan Agui, Mongolia. In P.C. Mitchell, H.M. Ambrose, ed. Proceedings of the Buffalo Archaeometry Symposium, SUNY Buffalo, 1998. University of Buffalo Press, Buffalo, p. 1-22.

Blackwell, B.A., Kim, T.W., Schwarcz, H.P., Lebel, S., Wilson, L. 1996, ESR (electron spin resonance) dating mammalian teeth from the Middle Paleolithic site, Bau de l'Aubesier, Provence. LED 96, 8th International Conference on Luminiscence and Electron Spin Resonance Dating, Canberra.

Blackwell, B.A.B., Leung, H.Y.M., Skinner, A.R., Schwarcz, H.P., Lebel, S., Valladas, H., Blickstein, J.I.B, Divjak, M.N., 2000, External dose rate determinations for ESR dating at Bau de l'Aubesier, Provence, Quaternary International v. 68, p. 345-361.

Blackwell, B.A.B., Skinner, A.R., Blickstein, J.I.B., Lebel, S., Leung, H.Y.M., 2001a, ESR isochron analyses at Bau de l'Aubesier, Provence: Clues to U uptake in fossil teeth. Geoarchaeology v. 16, p. 719-761.

Blackwell, B.A.B., Skinner, A.R., Blickstein, J.I.B., 2001b, ESR isochron exercises: How accurately do modern dose rate measurements reflect paleodose rates? Quaternary Science Reviews (Quaternary Geochronology) v. 20, p. 1031-1039.

Blackwell, B.A.B.,Fevrier, S. , Blickstein, J.I.B., Paddayya, K., Petraglia, M., Jhaldiyal, R., Skinner, A.R., 2001c, ESR dating of an Acheulean quarry site at Isampur, India. Paleoanthropology Society, Kansas City, MO. Journal of Human Evolution v. 40 p. A3.

Blackweell, B.A.B., Spalding, C.N., Blickstein, J.I.B., Latham, A.G., Quinney, P., Skinner, A.R., Kuykendall, K.L., Reed, K.E., 2001d, ESR dating the homind-bearing breccias at the Makapansgat Limeworks Cave, South Africa, Paleoanthropology Society, Kansas City, MO, Journal of Human Evolution, v. 40, p. A3-4.

Blackwell, B.A.B., Condiles, A.P., Skinner, A.R., Blickstein, J.I.B., 2002, ESR dating of dentine: Triumphs and tribulations. Paleoanthropology Society, Denver. Journal of Human Evolution v. 41 p. A5.

Brown, G.W., 2000, Teaching Archaeology. Eric Clearing House for Social Studies, Bloomington.

Howard Hughes Medical Institute, 1997, Science Careers: Future Trends and Current Realities (Undergraduate and PreCollege Program Directors Meeting), Chevy Chase.

Lau, B., Blackwell, B.A.B., Schwarcz, H.P., Turk, I., Blickstein, J.I., 1997, Dating a flautist? Using ESR (electron spin resonance) in the Mousterian cave deposits at Divje Babe I, Slovenia. Geoarchaeology v. 12, p. 507-536.

Maurer, M.J., 2000, Integrating Science Education and Career and Technical Education. US Dept. of Educations, Columbus.

Mass, S.V., Blackwell, B.A.B., Rosenwasser, N.L., Golovanova, L.V., Doronichev, V.B., Skinner, A.R., Blickstein, J.I.B., 2002, ESR dating of Paleolithic sites in the Northern Caucasus, Russia, Geological Society of America Abstracts with Program, v. 34, p. A184.

Skinner, A.R., Hays, R.L., Masao, F., Blackwell, B.A.B., in press, 2003, Dating the Naisiusiu Beds, Olduvai Gorge, by electron spin resonance (ESR), Quaternary Science Reviews (Quaternary Geochronology), v. 22.

Paddayya, K., Blackwell, B.A.B., Jhaldiyal, R., Petraglia, M.D., Fevrier, S., Chaderton, D.A., Blickstein, J.I.B., Skinner, A.F.R., 2002,. Recent findings on the Acheulian culture of the Hungsi and Baichbal valleys, Karnataka, with special reference to the Isampur excavation and its dating, Current Science v. 83, p. 641-647.

Roser, S.V., ed., 1995. Teaching the Majority: Breaking the Gender Barrier in Science, Mathematics, and Engineering, New York, Teachers College Press, 264 pp.

Steinberg, J., 2002. The Gatekeepers: Inside the Admissions Process of a Premier College, New York, Viking Press.

Turk, I., Skaberne, D., Blackwell, B.A.B., Dirjec, J., 2001, Morphometric and chronostratigraphic sedimentary analyses and paleoclimatic interpretations for the profile at Divje Babe I, Slovenia, Arheološki vestnik v. 52, p. 223-249.

Turk, I., Skaberne, D., Dirjec, J., Blackwell, B.A.B., 2002, Assessing humidity in an Upper Pleistocene karst environment, Palaeoclimates and palaeomicro-environments at Divje Babe I, Slovenia, Acta carsologica, v. 31, p. 139-175.