ENGAGEMENT IN AUTHENTIC GEOSCIENCE RESEARCH: EVALUATION OF RESEARCH EXPERIENCES OF UNDERGRADUATES AND SECONDARY TEACHERS

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ABSTRACT

This paper reports findings of the first year of a three-year summer geoscience program funded under the National Science Foundation Research Experiences for Undergraduates (NSF-REU) initiative. In this program, undergraduates and high school teachers work with a consortium of faculty from five southern colleges and universities. Eight undergraduates and four high school teachers engaged in four research projects initiated by faculty teams. This paper examines the effect of the program on the participants' interest in research, career plans, and attitude toward science. Participants working on three projects increased their interest in research, with two thirds of the participants changing career plans to become more research oriented. They reported that they enjoyed being part of authentic research in which they could take initiative and felt a sense of ownership in their projects. Due to less faculty availability, the fourth group had less opportunity to function as genuine partners in research. While participants in this group appreciated the opportunity to use sophisticated instruments, they had little chance to test their own ideas and gained only a limited understanding of how their tests fit into the research. Their interest in research did not increase. Implications for providing authentic research opportunities are discussed.

Keywords: education – science; - geoscience; - undergraduate; - testing and evaluation.

> "Doing science —- conducting actual research side by side with researchers —- is perhaps the best way to achieve scientific literacy."
> (Duchovany and Joyce, 2000).

This paper reports findings of the first year of a summer geoscience research program, funded under the National Science Foundation Research Experiences for Undergraduates (NSF-REU) initiative. The program involved undergraduates, who could earn directed studies credits, and high school teachers, who could earn staff development units (SDU's), in collaborative research with a consortium of faculty from five southern colleges and universities, one research university and the rest without sophisticated research facilities. The purpose of this paper is to evaluate the research experiences of the undergraduates and teachers.

The National Science Education Standards (National Research Council, 1996) provide guidelines for how science should be taught from kindergarten through twelfth grade. They focus on making science meaningful and accessible to all students through inquiry methods, making learning active, and building upon what students already know as they construct their own understandings. But science education reform cannot end at twelfth grade, according to the *College Pathways to the Science Education Standards* (Siebert and McIntosh, 2001): "To support change in K-12, we must change the way that science is taught at the college level." One suggested change is to make university laboratory exercises inquiry-oriented with more opportunity to engage in meaningful research. The structured nature of the traditional laboratory exercise expects the student to generate a correct answer and usually fails to give students a chance to witness or participate in the process of framing questions for further investigation. Some universities have attempted to make laboratory experiences more open-ended by building research projects, either real (Wimmers, 2001) or simulated (Sticker, 2002), into the coursework and by including final reports and poster sessions to simulate communicating results as a member of a scientific community (Knabb, 1997/1998; Stukus and Lennox, 1995). Involvement in research allows students to experience the excitement of behaving like a scientist and to figure out something which is meaningful to them. Examples of research in geology courses include field studies such as the chemical analysis of a pond (Carlson, 1999), collecting data from laboratory samples, and analysis of data from the literature (Mayborn and Lesher, 2000). Computer modeling is sometimes used for undergraduate research because computers are "readily available, inexpensive, and very powerful" (Amenta, Holyoke, Krohn, Bonder, and Leopold, 1997) and because modeling can enable study of processes that are not easily replicated in physical experiments.

Undergraduate research experience can also be provided through summer research programs. Participation in volunteer projects such as the Wagon Rock weekend project (Anderson, Hickson, Crider, and Graham, 1999) and various summer field camps and internships provide students with field experiences. One of the early NSF-REU programs (Herrick, 1991), found that a summer research experience emphasizing participation and discovery in chemistry was an effective tool in encouraging students to pursue advanced degrees in chemistry.

Teachers of secondary school science also benefit from research experience (NSF, 1996; NSF, 1997), and they can share these benefits with their students. Teachers often have learned geology through textbooks and planned laboratory experiences and have had little experience with true inquiry. In implementing the National Science Standards (National Research Council, 1996) at the high school level, the following instructional strategy is recommended: "Each concept should be

illustrated by student experimentation, followed by data collection in the local community, before students are encouraged to extend their understandings to the Earth system. Where classrooms experiments are not possible (such as in tectonics), data from real-world situations (such as earthquakes) provide relevant opportunities for discovery" (Texley and Wild, 1997). For teachers to facilitate student experimentation, it is important for the teacher to know "not just science facts, but just as important, the methods and process of research, what scientists and engineers do...." (NSF, 1996). A research setting is the best place for the science teacher to truly appreciate how the process of inquiry plays out in scientific investigation. Without this appreciation, teachers are not able to adequately convey the nature of science to their students. In addition, being involved in research offers the science teacher a chance to develop an avocation in earth sciences and the opportunity to tap into the societal prestige that science enjoys.

Involvement in research may be a way to increase interest in science in general. Piaget (1969/1970) stated, "True interest appears when the self identifies itself with ideas or objects, when it finds in them a means of expression and they become a necessary form of fuel for its activity." This "law of interest... controls the intellectual functioning" of both children and adults. Jarrett (1999) found that pre-service teachers increased interest in science through an inquiry oriented course designed to stimulate curiosity. Research on interest suggests that: (a) "interest is a phenomenon that emerges from an individual's interaction with his or her environment" (Krapp et al, 1992), (b) interest is an enduring "disposition" (Krapp et al., 1992), and (c) interest motivates behavior (Deci, 1992). If the above connections are accurate, the following might be said about interest in science: Science interest can be developed through interaction with fascinating phenomena. Once an interest in science is developed, people make the effort to seek out additional scientific information and science related experiences, thus further deepening science interest. If students increase interest in scientific research through involvement in real research projects, they may be more interested in careers in research. Teachers who enjoy and appreciate scientific research may be more motivated to do inquiry science with their students. If this hypothesized connection between interest and action is accurate, a key to effective science education may be to ensure that those who teach science have experiences that make them interested in research.

Various factors embedded in the research experience may affect the development of interest in research. One factor is the specific culture in the laboratory. In a case study of a high school student working as an apprentice in a university research laboratory, Bleicher (1996) studied the laboratory as a "complex social and cultural system" in which there were special norms and expectations and in which communication between researchers and students could constrain or support learning. A laboratory culture which is welcoming and where lines of communication between students and faculty are open may promote interest in future careers in research.

The quality and quantity of mentoring are also keys to the success of student research programs. Results from a survey of undergraduate researchers suggests that good mentoring involves getting to know the students as individuals, respecting them as colleagues, and "providing opportunities that will challenge them but not overwhelm them" (Shellito et al., 2001). Most of the faculty researchers who were interviewed as part of the same study indicated that "mentor availability is the key to a student's successful research experience" (Shellito et al., 2001).

How participants see their roles as they engage in research may also affect their level of interest in research. Bottcher (1971) surveyed students working with scientists and found that most saw themselves as members of a research team but that a small percentage saw themselves as laboratory assistants or temporary helpers. People who are truly part of a team have their voices heard and develop feelings of ownership about the outcomes. Empowerment theory and research indicate that feeling that one can make a difference is important in teaching (Kreisberg, 1992) and in other occupations (Dew, 1997). Empowering teachers is associated with teacher retention (Shen, 1997); empowering parents, students, and community members can transform schools and communities (Delgado-Gaitan, 1993; Mercado, 1993). Students surveyed by Shellito et al. (2001) especially valued the opportunity to work independently with only limited supervision from the mentor. As stated by one undergraduate researcher, "I got to be in charge of my own project once I learned how it worked and they [faculty mentors] valued my opinion..."

In the present project, secondary teachers and undergraduates were engaged as team members in authentic geoscience research. For undergraduates, such involvement can introduce students into the culture of research, possibly increasing interest in a profession in the geosciences. For teachers, engagement in true inquiry science can affect teaching methods, inspiring a future generation to become more interested in science. This paper has two purposes: (a) to assess the effect of the program in general and research team membership in particular on participants' general evaluation of their research, understanding of their research, interest in science, interest in research, and career plans and (b) to interpret the findings through the general lens of the program evaluation in order to make recommendations for subsequent years of the project.

METHOD

Participants - Eight undergraduates and four teachers (all referred to as participants) were accepted for the eight-week research program. All received $2000 stipends. Some undergraduates received course credit; the teachers received SDU's. The group consisted of five women and seven men. The ethnic breakdown of the group was nine Caucasians, one African, and two African Americans.

The undergraduates ranged in age from 19 to 26; the youngest had just completed his freshman year. Six had geology related majors (geology, math/geology, earth and atmospheric science, or earth science with broad field education certification). The other two participants had majors in environmental science with a concentration in chemistry and "undecided, perhaps biology or water resource management."

The teachers ranged in age from 35 to 54; all four had Masters degrees, one an MBA and the rest in science education. One had an undergraduate major in physics; the rest had general science education undergraduate degrees. None had specialized in geology. Three teachers

are on the faculty in regular high schools; the fourth teaches in an alternative school. Unfortunately, one teacher injured her back and withdrew three weeks before the end of the program.

Research Teams - Together with 10 faculty members (nine in geology and one in geography) from the five southern colleges and universities involved in the consortium, the participants divided into research teams to work on four regional geoscience projects proposed by various groupings of faculty from the five institutions. After hearing presentations by the faculty, participants chose the research team on which they wished to work. The projects included an analysis of fluid inclusions in core samples of high grade metamorphic rocks, a study of clay minerals and fossils in a limestone deposit from the Georgia coastal plain, an analysis of heavy metal concentrations in urban and suburban watersheds, and a study of the origin and structural features of a unique section of the Southern Appalachian Piedmont. Although the faculty had planned the research projects, the topics were broad enough to allow input from the participants, who were expected to function as team members rather than as student assistants. Some faculty members worked with more than one project.

The composition of the teams was as follows:

- Team A - three faculty and two participants: one male and one female undergraduate.
- Team B - three faculty, three participants: one male and one female undergraduate, and a male teacher.
- Team C - three faculty, four male participants: two undergraduates, and two teachers.
- Team D - two faculty, one masters level graduate assistant and three female participants: two undergraduates, and one teacher.

The participants worked full time, approximately 40 hours a week. Three of the four groups had at least one field trip for collecting samples. Only Team A worked entirely from samples which had been obtained previously. The teams used such sophisticated laboratory techniques as scanning electron microscopy, optical microscopy, x-ray diffraction, computer modeling, x-ray fluorescence spectrometry, inductively coupled plasma mass spectroscopy, Geographical Information System analysis and the use of satellite images. Members of all the teams were also required to do some library research on topics related to their topic. In addition to engagement in their own research, participants attended weekly colloquia featuring research of other faculty members, a weekly philosophy of geosciences reading seminar, and weekly research group meetings where participants reported on their research. Students wrote individual papers on their research and each team presented its findings on the final day of the program.

Evaluation Procedures - The evaluation had both formative and summative aspects and included both quantitative and qualitative methods. The findings reported here concern interest in science and research, satisfaction with various aspects of the program, and changes in career plans. On the first day of the program, participants filled out a questionnaire on their background experiences, and at the beginning and at the end of the program, they rated their interest in various scientific fields and in research in general on five-point Likert Scales ranging from *low* to *high*. Half-way through the program, participants, identified only by team, filled out a questionnaire on which they evaluated various aspects of the program. Included in this questionnaire were two questions to be answered on a five-point Likert Scale concerning their specific research project. The first question, "How would you evaluate your research work?" was rated on a continuum between *uninteresting* and *interesting*. The second question, "How well do you understand the research you are doing?" was rated on a continuum between *am confused* and *understand*. At about the same time, each team was interviewed for 20-30 minutes, and responses were tape recorded. The interviews were informal and included questions such as: What are you doing? What are you learning? Are you learning what you wanted to learn? What suggestions do you have? As part of the formative evaluation, general responses on the questionnaires and interviews were shared with the project director (co-author).

At the end of the program, participants, identified only by team, evaluated the same aspects of the program they evaluated at the half-way point and answered open ended questions on their likes and dislikes as well as their relationship with the faculty. They also answered questions about their career plans and whether the program had changed theses plans.

The project evaluator (first author, a science educator) attended the opening session, the philosophy of geosciences seminar, social events, the final session where students presented their research, and most of the weekly colloquia and research group meetings. At these meetings and in her interviews with the teams, she observed levels of interest and participation and interactions between the undergraduates and teachers.

RESULTS

From the beginning to the end of the project, participants did not change in "interest in science." Understandably, they were initially interested in science in general, especially in earth science, and that interest remained high. Because of the small number of subjects, statistical tests of significance could not be used to compare evaluation responses between teams. Table 1 shows mean scores of the teams at the middle and end of the program on the answers to the following: (a) two questions on personal interest asked pre- and post-project and (b) two questions concerning their research experience asked in the middle and again at the end of the program.

An examination of the means shows that Teams B and C were similar in evaluation of their research work (mean = 4.86) and in understanding (mean = 4.57). In the interviews and in their mid-summer and final evaluations, these team members made only positive comments such as: "I am learning a massive amount." "I can take initiative." "This is a lot of fun." "I am learning good research techniques." "I am learning a lot from the faculty and the faculty is learning too." "For the project to progress, the faculty needs to learn from our mistakes." "I am forcing myself to read a doctoral level book because I want to." "I like the culture…I just love it." "The professors are awesome." "This is ground breaking research."

Also, Teams A and D appear similar at the end of the program in evaluation of their research. Both teams evaluated their work as 4 and also rated their

5 Point Likert Scale Responses low = 1, high = 5		Team A	Team B	Team C	Team D
How would you rate your interest in earth science? (high/low)	Pre	4.5	4.67	4.75	4.5
	Post	5	5	5	3
How would you rate your interest in research? (high/low)	Pre	4	5	3.25	4
	Post	5	5	5	2.5
How would you evalutate your research work? (uninteresting/interesting)	Middle	5	5	4.5	4
	End	4	5	5	4
How well do yu understand the research you are/were doing? (am confused/understand)	Middle	4.5	4.33	4.5	3.67
	End	4	5	4.25	4

Table 1. Mean responses by research team to four questions on interest and understanding.

understanding of their research as 4 (both on a five point scale). Written comments from Team A members were predominantly positive. They said: "I like working in the lab." "I like computer work." "Some of the work is pretty slow and when you do it all day it can get a bit long. Other than that it's great." "I enjoy working in a research community." "I actually do work instead of running errands as I did on a previous internship. I am learning a lot." However, one comment hinted that team members might have liked to have worked with their own samples: "I've never been on a geology field trip. It might be kind of fun to see the site where the core samples come from."

Written comments from the Team D were mixed. Due to changes in faculty responsibilities, including travel abroad and other projects, this team had less consistent faculty involvement than the other teams. Much of their supervision came from a graduate student who was able to help the participants collect their data and run the tests needed for analyzing their samples, but who could not provide the kind of mentoring suggested in Shellito et al. (2001). In commenting on their research work and their understanding of the research the participants said: "Definitely interested in [the topic]. Some of the specific work is not very engrossing." "I understand the specific work we're doing although the objective is slightly unclear." "I think the objectives were never really explained. We worked with several people whose topics never related." "Many of the people we work with come and go so we have little in the way of direction." "I am slightly disappointed in that the people who work on our program seem to do very minimal work with us."

On interest in research, participants from three Teams A, B, and C appear to be different from Team D participants. The former increased their interest in research, all of them giving a 5 point rating at the end of the program. Two-thirds of these participants said that the research program had influenced their career plans. Two undergraduates expressed interest in becoming university professors. One teacher said he was considering a return to graduate school in geology. One undergraduate decided that she was now more interested in geography than geology, and one wished to focus on geophysics research. The participants enjoyed being part of authentic research and enthusiastically reported that they felt a sense of ownership in their projects. They appreciated that their ideas were respected, that the faculty was available for questions, and that they worked with faculty as collaborative teams. Several asked whether they could return next year in order to complete THEIR research and three participants (two teachers and an undergraduate) applied for the program the following summer. Three others who were extremely interested in continuing, but were not eligible because they were graduating, subsequently entered geology graduate programs. Members of Teams A, B, and C presented their scientific findings at conferences of the Geological Society of America: Southeastern Section and the American Geophysical Union. Their abstracts are included in the proceedings volume with students and faculty as joint authors.

Team D members did not rate their interest in research as positively as the other teams. The participants did their expected research assignments and produced an excellent final presentation. However, they were the only group that did not submit their research for presentation at a conference. Although they said they were glad they participated, the two undergraduates (the teacher with the back injury had been on this team) decreased in interest in research. One stated: "I know that research is not what I would like to have a career with…I am more interested in policy."

Interviews conducted half way through the program afforded a clue to the evaluator that Team D was having an experience somewhat different from the other teams. The other teams invited the evaluator into "their labs" where they shared their enthusiasm for their project and pointed out (and in some case demonstrated) the instruments they were using. Team D said they had no laboratory space and suggested conducting the interview in a classroom. They said that they worked with equipment in various laboratories but that they had not been given a key to any of the laboratories. They complained that they sometimes had to wait with nothing to do while finding someone with a key. In the interview and in their written comments, they said that they enjoyed learning to use sophisticated instruments

but that they did not know why they were doing the tests they were doing. They did not "know how things tie together."

All participants in the four teams said they would recommend the program to a friend. When asked what they liked best, most commented on contacts with the faculty and the fact that they were doing real research. Following are some typical comments written on their final evaluation questionnaire:

- [I liked] the exposure to proper laboratory techniques, the assemblage of information and data, experience writing scientific papers, giving presentations. [Team B]
- I learned a lot from the ... program; I like the fact that I actually did my own research. [Team A]
- Enjoyed all. Very educational and informative. Rejuvenates interest in science and teaching. [Team C]
- I enjoyed greatly that I got to work with professors and was able to work with equipment that would only be used with graduate students. I loved the possibility of completing important research. [Team D]

Team members were not asked to rate one another and the final evaluations of the project were identified only by team. However, general observations during the interviews, the presentations, and other events suggest that the teachers and undergraduates worked well together in two of the three teams which were made up of undergraduates and teachers. They divided the work and appeared to collaborate well. These are the teams in which all members rated their experience highly. All four teachers inquired about participating again the following year, although only one was actually able to devote a second summer to the project. This teacher identified many ways in which he incorporated his research experience into the classroom, involving his students in more authentic research. In group D, the teacher dropped out three weeks from the end due to health problems. Her group members appeared to feel abandoned and raised questions as to whether she was really too ill to continue.

DISCUSSION

Overall, the participants felt positive about their experience with the program. All said they would recommend it to others. One member of Team D who said her project was "lacking structure and supervision" added: "excellent experience for anyone to work with state-of-the-art equipment. Fun!" In three of the four teams (Teams A, B, and C), students felt that they were an important part of a faculty/student collaboration. They were proud of their lab spaces and appreciated the collegial relationship with the faculty. Although the research topics had been proposed by the faculty, participants felt ownership of their projects. Some of the students traveled to regional or national conferences, where they presented their results. A paragraph from the application essay of a student from Team A, who applied to return for the second year of the program, expresses well the value of engagement in REAL research:

> I think that one of the most important benefits of the ... program is the actual hands-on experience provided to the participants. I have talked to students who have interned with petroleum companies during a summer, and they claim that most of the activity was predominantly "busy work" which I find to be meaningless in most cases. As I describe to them the research that I performed with the ... program, they seem impressed and at times jealous of my accomplishments. I feel that this research experience is unique in the fact that the participants partake in a thorough research project.

The teams differed in gender and in the number of participants. They were also self-selected. Therefore, various interpretations for the different results are possible. The samples are very small, making any interpretation tentative. However, we suggest the following explanation for the differences between groups. The two teams who were most positive in rating their interest in and understanding of the research did their own field collecting, worked with a variety of instruments, and had a partnership relationship with faculty. They had the most complete hands-on experience, from the collection of the specimens to the presentation of the results. This total inclusion in the research may have affected their positive feelings.

True inquiry may have inspired students and teachers in three of the groups to become more interested in doing research. Difficulties in providing consistent mentoring of Team D allowed for some unplanned experimentation with issues of authentic inquiry and empowerment. The lack of a key to the lab is perhaps symbolic of the lack of full integration into the culture of the laboratory, considered important by Bleicher (1996). Although Team D participants had access to community research space, they did not have their "own" space. They also had less access to their faculty mentors and lacked an understanding of how their lab tests fit into "the big picture." They did not feel empowered. This team functioned more like traditional lab assistants than as partners in research. Participants in Team D found their work interesting, but their work did not inspire their interest in research. These feelings were evident even before the teacher dropped out.

The program described in this paper showed that students, teachers, and university faculty can be true partners in geoscience research and that such partnerships can increase interest in research for students and teachers and help students clarify career plans, as found in Herrick (1991). Differences in the teams allowed for some unexpected experimentation with issues of authentic inquiry and empowerment. The most successful teams encouraged initiative: authentic inquiry. The work done by the other team was a bit like a traditional laboratory exercise in which students run experiments but do not initiate authentic research. True inquiry inspired students and teachers to become researchers.

POSTSCRIPT

The experience of the first summer led to several important changes in the project in subsequent years. The first year, Team A had been the only team that analyzed laboratory samples which they had not collected. By the third year, the participants engaging in

the same research topic collected their own samples, enabling them to better understand the entire research process, including collection of samples, laboratory analyses, and presentation of findings. After analyzing rocks which they had collected, several members of this team commented that it was interesting to be able to picture how their samples fit with the geology of the area.

The experience of the first year prompted the addition of an another faculty member, whom project faculty knew had an interest in the topic being researched by Team D. The new faculty member, a professor at a small college, devoted approximately three days a week to the project, traveling with the participants on many of their data collection trips, helping them with the analyses of their samples, and answering their many questions about careers in geology. As found in the survey results of Shellito et al. (2001), the availability of a mentor was important to participants in this team. Symbolic of the change in atmosphere, when the evaluator interviewed members of this team, one of the students let her into a laboratory room where they sometimes worked, using a keypad code.

Although project evaluation by the faculty mentors is outside the scope of this paper, faculty satisfaction, both personal and professional, is critical to the continuation of authentic research collaborations with undergraduates and teachers. The quality of the research produced in collaboration with students and teachers as well as the friendships which developed among faculty prompted the faculty to seek and obtain funding for another three year cycle.

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