Evaluation of the Impact of the NWC REU Program Compared with Other Undergraduate Research Experiences

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ABSTRACT

Undergraduate research is increasingly valued as a critical component of a good undergraduate science education. Through research, it is expected that students will develop significant knowledge, skills and dispositions. The NSF REU provides such an opportunity for college students. One of the authors recently reported an analysis of applicant characteristics, "best practices" implemented since 2001, and new additions to the program. This paper provides a research-based synthesis on the effectiveness of REU programs in general, summarizes the history of the National Weather Center REU program and its positive impact on students, describes the unique characteristics of the current program, and uses students' written comments to evaluate the program's effectiveness. It was found that REU students were significantly more committed to attend graduate school at the end of the program. No statistically significant difference was found on the students' career plans and interest in becoming research scientists before and after the program. A qualitative analysis provides a context from which the statistical data can be interpreted.

INTRODUCTION

Undergraduate research is increasingly valued as a critical component of a good undergraduate science education (Halstead, 1997). Through research, it is expected that students will develop a number of behaviors and knowledge, among them an ability to do science, theoretical and practical subject matter knowledge, research and communication skills, independent thought, creativity, and a positive disposition toward the discipline (Kardash, 2000).

The involvement of undergraduate students in research may be summarized in three metaphors: (a) the student as passive learner, where the student is taking courses in subject matter and research methods, (b) the student as a low-skill worker, where the student works as a laboratory technician and is not considered to have the skills needed for significant contributions, and (c) the student as colleague, where the student takes a significant role in many phases of the research process and initiative is rewarded (Kremer and Bringle, 1990). Research suggests that the colleague model of undergraduate research, an essential feature in many Research Experiences for Undergraduates (REU) programs, has significant benefits for students (Kardash, 2000; Seymour et al, 2004).

Most REU programs follow a four-step structure of collaboration that includes: (a) identifying and acquiring a disciplinary or interdisciplinary methodology, (b) setting out a concrete investigative problem, (c) carrying out an actual project, and (d) sharing the discovery with peers and the professional community (Dotterer, 2002). Furthermore, Hakim (1998) characterized REU experiences as resting in four assumptions: (a) that the interaction between the undergraduate research intern and the mentor is focused on student learning, (b) that the research experience will lead to meaningful contributions by the student to the research project, (c) that the procedures and methods used as tools of inquiry by the student are consistent with current practices in the discipline, and (d) that the research experience will culminate in a tangible product that is to be critiqued by other members of the discipline.

Two pieces of evidence strongly support the importance of undergraduate research. First, all seven principles for good practice in undergraduate education described by Chickering and Gamson (1999) in their seminal paper apply directly to undergraduate research: encouraging contact between students and faculty, developing reciprocity and cooperation among students, using active learning techniques, giving prompt feedback, emphasizing time on task, communicating high expectations, and respecting diverse talents and ways of learning. Second, several professional organizations have been created to foster undergraduate research, among them the National Conference on Undergraduate Research and the Council on Undergraduate Research.

In 2005, one of the authors described and summarized the current REU program at the National Weather Center (NWC), but no assessment report was included (Zaras, 2005). The purpose of the paper is to share with the geoscience education community the evaluation results of the National Weather Center's REU program. Specifically, we are guided by the following questions:

- Is there a statistically significant difference in graduate school plans for 2001-2005 students before and after the summer research experience?
- Is there a statistically significant difference in career plans for 2001-2005 students before and after the summer research experience?
- Is there a statistically significant difference in 2001-2005 students' perceptions of their potential for scientific research before and after the summer research experience?
- In what ways do students' written comments reflect the impact of the REU experience?

This study is innovative in two ways. First, most evaluations of REU programs available in the literature come from biology, chemistry, geology, physics, and engineering. This study seeks to determine how the REU experience impacts students in meteorology, a field with many overlapping career types. Second, the study combines quantitative and qualitative components to

Student name and affiliation	Title of paper	Presentation venue and year
Blahyj, D. M. SUNY-Brockport	Severe weather associated with a bow echo and a series of mesolows	21st Conference on Severe Local Storms, 2002
Meyer, C.L. Boston College	A hazard model for tornado occurrence in the United States	16th Conference on Probability and Statistics, 2002
Metz, N. D. Valparaiso University	Extratropical cyclones with warm-sector baroclinic zones and their relationship to severe weather	20th Conference on Weather Analysis and Forecasting, 2004
Horgan, K. L. North Carolina State University	A five-year climatology of elevated severe convective storms in the United States east of the Rocky Mountains	Severe Local Storms Symposium, 2006
Schumacher, R. S. Valparaiso University	Upper-tropospheric inertial instability: climatology and possible relationship to severe weather	9th Conference on Mesoscale Processes, 2001
Mazur, R. Northern Illinois University	Quality control of radar data to improve mesocyclone detection	20th International Conference on Interactive Information and Processing Systems, 2004

Table 1. Typical NWC REU student papers and venues they were presented

create a clearer picture of the impact of the REU program on meteorology students.

REVIEWING EFFECTIVENESS OF REU PROGRAMS

The need to justify the financial, technical, and human investment in undergraduate research programs renders their assessment more important (Kardash, 2000; Nnadozie, Ishiyama, and Chon, 2000). Fortunately, there is a significant body of literature supporting the proposition that REU is an educational and personal-growth experience with many transferable benefits (Bresette and Breton, 2001; Seymour et al, 2004).

One of the transferable benefits for students is they become capable of producing a professional-quality research product through their writing experience, usually papers (Shellito, 2001). An indicator of the quality of these papers and of the REU experience is that papers are often accepted for presentation at professional conferences. A subgroup of these is accepted for publication in professional journals (Kinkead, 2003; Kremer and Bringle, 1990; Lanza and Smith, 1988). In contrast, research experiences that do not require the preparation of a publishable paper are not as useful in helping students to prepare and be accepted to graduate school (Nnadozie, Ishiyama, and Chon, 2000). A list of typical NWC REU student papers and the venues they were presented is summarized in Table 1.

Another benefit is that students perceive that their research skills have improved significantly after the experience when compared with those of peers who did not participate in an REU program (Bauer and Bennett, 2003; Gawel and Greengrove, 2005; Kremer and Bringle, 1990). Students report a direct, independent, hands-on engagement in the practice of the science that emphasized learning by doing (Dotterer, 2002; Shellito et al, 2001). They also reported the mastering of complex scientific concepts and the development of advanced critical thinking skills (Ishiyama, 2002). In some cases, research experiences can go beyond the summer, with students working on either extensions of their projects or brand-new ones (Lanza and Smith, 1988).

REU participants tend to use their experience to make important decisions about future goals. Students report that the research experience helped them to clarify, refine, or confirm their pre-existing choice of career direction (Alexander et al, 1996; Seymour et al, 2004). They also report being more confident about their potential success in graduate school (Gentile, 1988; Kremer and Bringle, 1990). Bauer and Bennett (2003) reported that University of Delaware alumni who had undergraduate research experience were significantly more likely to pursue graduate education and were twice as likely to complete doctoral studies compared with alumni with no undergraduate research experience. Interestingly, Mortenson (1988) reported that two of his REU mentors participated in similar programs as undergraduates, and cited their experiences as a major factor in their career choice. This is also the case with the NWC REU program, where one of the authors (LaDue) was an REU student in 1988 and now runs an REU program.

Students report that participating in undergraduate research gives a sense of ownership of the results, intrinsic motivation, and a sense of the real struggle scientists face as some experiments do not turn out as expected (Alexander et al, 1996; Kinkead, 2003; Lanza, 1988; Seymour et al, 2004). Undergraduate students learn a great deal from mistakes and surprises.

Undergraduate research has also increased the retention and graduation of underrepresented students in certain disciplines, including science (Jonides, 1995; Nagda et al, 1998). Another group that also benefits from REU programs is low-income students. The stipends paid to these students make it practical for them to engage in research full-time during the summer (Gentile, 1988).

As research develops, it is possible for faculty and students to face ethical dilemmas. As a consequence, ethical considerations are explored, discussed, and decisions are made based on careful deliberation. This is a unique opportunity for students to get acquainted with real examples of ethical struggle and learn from them (Kinkead, 2003; Shachter, 2003).

Undergraduate research programs not only have a positive effect on the participating students, but on some of their peers as well. For example, Gentile (1988) reported that other science majors and non-science majors attended symposia lead by REU students to present their research results. Gentile (1988) also noticed that research participants become leaders in their department and models to other students. This is also the case with some of the NWC REU students, who become

Workshops:
- Being a Scientist
- Introduction to Statistics
- Introduction to UNIX
- Scientific Communication
- Severe Weather Forecasting
- Reading on the Frontier: Critically Reading a Journal Article

Lectures and Panel Discussions:
- Career Panel Discussion
- Developing a research problem
- Dual-Polarized Radar
- Economics in Meteorology
- Introduction to Radar
- National Council of Industrial Meteorologists Student Talk
- Overview of the Engineering Research Center for Collaborative Adaptive Sensing of the Atmosphere
- Science and Public Policy of Climate Change
- Scientific Leadership
- Thunderstorm Electrification and Lightning Experiment (TELEX)
- The Ins and Outs of Applying to Graduate School
- The Oklahoma Mesonet

Tours:
- NOAA Norman's Five Facilities
- OU School of Meteorology
- OU Supercomputing Center
- SMART-Radar Mobile Research Radars
- Phased Array Radar
- Thunderstorm Electrification and Lightning Experiment (TELEX) Field Equipment
- WeatherNews, Inc., Norman, Oklahoma Facility

Figure 1. Enrichment activities provided for REU students since 2001

leaders in their local American Meteorological Society (AMS) chapters.

Despite the large number of reports evaluating REU experiences in positive terms, some specific outcomes are harder to measure. Part of the reason for this is the inappropriateness of standardized assessment methods given the varied backgrounds, preparations, knowledge, and experiences of both mentors and undergraduate researchers (Kardash, 2000). Some limiting factors in assessing the students' real gains produced by the research experience include small size groups and the absence of control group comparisons (Bauer and Bennett, 2003). Also, self-reporting and self-selection are problematic. However, as a whole the literature on REU experiences is overwhelmingly supportive.

HISTORICAL BACKGROUND OF THE NWC REU PROGRAM

In 1987, the National Severe Storms Laboratory (NSSL), one of the National Weather Center institutions, established a "summer employment program" for undergraduate students to address two important issues at the time: (a) the scarcity of undergraduate students, especially females and minorities, interested in meteorology; and (b) the inability of the educational system to introduce undergraduates to the "business of scientific research" (Lewis and Maddox, 1991). This program was designed to emulate similar programs in existence in the 1960s and 70s at the Experimental Meteorology Laboratory at Coral Gables, Florida, and to complement existing programs such as the National Center for Atmospheric Research's Summer Employment Program at Boulder, Colorado (Armhols and Woodley, 1975). Since 1991, most summer programs have been supported in part by a National Science Foundation REU grant.

The positive impact of the NWC REU program has been documented from its beginnings through student evaluations. For example, students from the first summer programs at NSSL expressed their unanimous appreciation for the learning and research opportunity provided and their "renewed enthusiasm for science and a better idea of where it fits into their future" (Lewis and Maddox, 1991, p. 1372). Eleven out of seventeen of the students who did summer research at NSSL were females or minorities.

Around the mid-1990s, Cortinas Jr. et al. (1996) summarized the successes of the NWC REU program up to then, and evaluated the 1995 program. Students' answers to pre- and post-program questionnaires were compared to determine if the goals of the program were met. It was found that the REU program reinforced most students' decision to attend graduate school, and that all students felt better informed about career options in meteorology. Some of them seriously considered a research career. Students' comments regarding the REU program were extremely positive. Similar reports of the continuing positive impact of previous REU programs were reported several years later at professional meteorology meetings (Palmer, 1999; Palmer, Stevenson, and Zaras, 2000).

In its latest form, the NWC REU program has continued to use mentor and student feedback in order to evaluate the program, and refine what are now identified as best practices (Zaras, 2005). In the last 5 years, the program has been structured so that students participate in numerous workshops, field trips, and lectures (see Figure 1). Most of these activities are specially tailored to avoid overwhelming students.

All students are required to complete a 10-page paper on their work, and to present their findings in a 12-minute presentation to mentors and other scientists at the end of the summer program. Since 2004, student travel is funded so that they can also present their findings at American Meteorological Society annual meetings.

Student recruitment efforts since 2001 have taken various forms. Information about the program was made available online; at exhibits in several professional meetings (e.g. National Society of Black Physicists, National Society of Hispanic Physicists, American Meteorological Society, American Indian Science and Engineering Society); through networking from scientists, professors, and alumni; and was sent to nearly 300 science, mathematics, secondary science education, computer science, and engineering departments across the United States, including tribal colleges and HBCUs. As a result, more than 470 students have applied to the program. Unfortunately, due to limited funding, only 23 males and 29 females from large and small universities and colleges across the nation have participated in the 2001-2005 programs.

The recruitment of mentors is a much easier task. All of the mentors are productive researchers in a variety of weather disciplines and have expressed their genuine interest in mentoring undergraduates. The mentors have represented most of the Federal, state, and university

Main REU Goal	N	Median ($\bar{x}$, σ) before NWC REU	Median ($\bar{x}$,σ) after NWC REU	Significance Level
Plans to attend graduate school	38	4.25 (4.46, 0.63)	5 (4.62, 0.60)	< 0.05 (W+=35, W-=136)
Well defined career plans	38	3 (3.02, 0.75)	3 (2.97, 1.12)	>0.05 (W+=132, W-=145)
Plans to become a research scientist	36	4 (3.83, 0.64)	4 (3.67, 0.85)	>0.05 (W+=94, W-=42)

Table 2. Statistics summary for research questions 1-3 (Main REU goals)

organizations that comprise the National Weather Center. Each year a mentor meeting is held before the program begins to talk about the nature of the program and make sure mentors understand what is expected of them.

Practice talk sessions are one of the successful features of our REU program. The purpose of these three practice talks is for students to get used to talking in front of an audience and to summarize their research achievements in a short format. In different sessions, students are required to: (a) summarize the relevance of their research topic, (b) present a progress report with a discussion of the challenges they were dealing with, and (c) present a detailed description of the research's theoretical background and methodology. The final presentation follows the format of a professional conference.

A few brainstorming sessions are another important aspect of the program, providing students an opportunity to ask questions and raise concerns in an informal forum. The sessions allow the REU director to explore what students do and do not understand about research, graduate schools, careers, and receive feedback on how the program is affecting them. The environment was one of openness and confidentiality.

METHODOLOGY

For the quantitative analysis, data collected from REU participants since 2001 was used. Fifty-six percent of the participants were female. About 10% of the participants identified themselves as members of an underrepresented group in science. Almost 91% of the participants had majors in meteorology or physics; the rest came from mathematics, chemistry, or geography. There was an even split between students who originated from teaching and research institutions. About 87% of the participants were junior or seniors.

For the qualitative analysis, only the survey comments from the 2004 participants were used as sources of data. That year, 60% of the participants were female, 90% were meteorology majors, and 80% were juniors or seniors. Students came from teaching and research universities located in Illinois, Indiana, Wisconsin, Pennsylvania, Oklahoma and Florida. All data collection was by means of initial, intermediate, and final surveys. The University of Oklahoma's Institutional Review Board approved this study.

To collect data about the students' plans for graduate school, career plans, and their perceived potential to become research scientists, a 5-point Likert scale was designed. In this scale, the extremes were defined as "no", corresponding to the number one, and "yes", corresponding to the number five. The number three, at the middle of the scale, was interpreted as "not sure".

As Likert scales were used, it was decided to use a non-parametric test to determine significant differences. The Wilcoxon matched-pairs signed-ranks test, a non-parametric version of a Student's t-test, is the appropriate test for ordinal data (Gibbons, 1993). This test uses a null hypothesis that the difference between the members of each pair of values has median value of zero. We selected an alpha level of 0.05 to balance the need for a relatively strict significance cutoff point with the reality of a small sample size and the use of a nonparametric test.

For the fourth research question, we used a written survey format to gather information from the participants. Participants were questioned about satisfactions and challenges related to their research projects, potential career plans, plans to attend graduate school, their presentations, and how much they learned about research in meteorology.

Qualitative data from surveys were combined to create case summaries of the summer experience of each participant in regard to the four research questions, an appropriate analysis procedure when individual differences may be important (Creswell, 1998). The goal was to explore participants' thinking behind their answers to the survey questions to see if other changes in students' attitudes and perceptions were not adequately measured by the Likert scale responses.

We did our best to assure that the survey used demonstrated a satisfactory level of validity and reliability. For example, all available students from a specific year were used as participants for the qualitative analysis. This might somewhat overcome self-selection limitations. The survey had clear instructions and straightforward questions to avoid confusion or misinterpretation. The questions, consistent with themes from the REU evaluation literature and specifically designed to fit the research objectives, were written by one of the authors, a person knowledgeable in meteorology, educational research, and the literature on undergraduate research evaluation.

QUANTITATIVE FINDINGS

Students were asked about plans to attend graduate school, whether they had well-defined career plans, and whether they saw themselves becoming research scientists at the beginning and at the end of the REU experience. Thirty-six students answered all questions. Table 2 summarizes the statistical results.

Regarding the question about plans to attend graduate school, on a 1 to 5 scale, the median response was 4.25 at the beginning of the program and 5 after the program (n = 38). In percentage terms, 10.5% of the participants lowered their final score and 36.8% increased their score at the end of the REU experience. This difference is statistically significant. It can be

	Pre-program Responses	Post-program Responses
Grad School Plans	5: Ph.D. "At this point I would like to..."	5: not sure how far "I am not yet sure if I will pursue a doctorate..."
Career Plans	4: do research in meteorology "Fairly well-defined career goals... I would like to conduct research..."	4: teach and do research "I have fairly well-defined career plans. I would like to teach meteorology and conduct research."
See Self as Scientist	4: yes "Yes, I think I could be..."	4: yes for at least part of career "I am fairly certain that, for at least part of my career, I will become a research scientist."
Scientist Description	- need diverse/well-rounded education - M.S. or doctorate - driven to learn more - possess thirst for knowledge	- want to know how concepts work - focused puzzle-solvers who try new ideas, often see them fail, occasionally come to new and meaningful conclusions - curious - desire to better world - cannot imagine thinking about same problem on daily basis

Table 3. Summary of pre- and post-program Likert score responses and explanations for Chris.

concluded that students came to the REU program with a good idea that they wanted to continue to graduate school and left more committed to attend graduate school.

Regarding the question about whether participants had well-defined career plans, the median response was 3 before and after the program (n = 38). In percentage terms, 28.9% of the participants lowered their final score and 31.6% increased their score at the end of the REU experience. This difference is not significant. It can be concluded that students might come into the REU program without a well-defined picture of their career plans and left the program without improving their career goals.

Students were also asked at the beginning and end of the REU experience whether they saw themselves becoming research scientists. The median response was 4 before and after the program (n = 36). In percentage terms, 27.8% of the participants lowered their final score and 16.7% increased their score at the end of the REU experience. This difference is not significant. It can be concluded that students completed the REU program but the experience did not significantly change their self-efficacy on becoming research scientists, which was relatively high to start with.

QUALITATIVE FINDINGS

In this section, three cases from the 2004 REU participants are presented as typical of the REU experience. The surveys provided an opportunity for students to elaborate on their Likert scale scores about their plans for graduate school and careers, and their perception of becoming a research scientist. The reported names of the participants are pseudonyms to assure the confidentiality of their responses.

Chris

Summary of pre-REU career ideas - As he came into the program, Chris had a somewhat complex view of what research is: "the work of research scientists would depend a lot on the type of research they are doing," followed by an example. Although he appeared certain that he wanted to obtain a Ph.D., marking a 5 on the Likert scale, there was a slight hint of hesitation regarding his plans to conduct research with the words, "at this point I would like to..."

Summary of post-REU career ideas - Chris now plainly states he is still unsure if he will pursue a doctorate: "I think [how far I go] will depend on how I feel about graduate school after being there for awhile, and what opportunities come up in the interim." When asked to elaborate, he says that his experiences "somehow made that conviction stronger." He is not sure how or why, though he suspected it was due to the interaction with a diverse set of meteorology professionals. The interesting parts have become "most of the field" by the end of REU. He has become interested in teaching, but he does not think he could give up research.

Note - Chris had the extra kick of affecting the direction of his research to an extent few students are able to do. He said, "I enjoyed my research project very much... making a contribution to the science and doing something that might actually be useful to forecasters some day."

Several months after the program ended, all 2004 participants went to the American Meteorological Society Annual Meeting. Chris found presenting a poster on his research to be extremely rewarding, writing, "At the poster session, I came to see why people were interested in my research, not just that they were interested. I came to see where in the field my research might fit in, and how it might be valuable to others." He said meeting professors and representatives from graduate schools to be "invaluable."

Changes - Most notable is that while he continues to be sure about research at the end of the summer, having had exposure to other, interesting careers in meteorology has challenged his convictions a little. Attending the professional conference increased his uncertainty about career direction, opening even more interesting career possibilities.

Ann

Summary of pre-REU career ideas - Ann is strongly oriented toward earning a Ph.D. because both of her

	Before	After
Grad School Plans	4: Ph.D. only comment is: "I like school a lot"	5: Meteorology, Ph.D., more certain exposure to people helped because graduate students at her school are on the other side of campus; things seemed "neat" here
Career Plans	2: anything but broadcast "Go to grad school, see where it takes me... could end up in academia or research position."	1: go to grad school, get a degree She cannot see beyond graduate school right now.
See Self as Scientist	4: "I like finding things out and working through things and I think figuring things out is interesting"	4: "I think research is neat."
Scientist Description	- smart, thorough, excited by dorky scientific things, motivated, creative, analytical	- silly, curious, focused, creative, innovative, critical, careful, thoughtful, open-minded.

Table 4. Summary of pre- and post-program survey Likert score responses and explanations for Ann.

	Before	After
Grad School Plans	5: definitely graduate school, probably Ph.D. "I've been a weather enthusiast since I was very young... Learning has always been a passion for me, so I see no reason to leave school."	4: most likely masters "Prior to the program, I really thought I wanted to pursue a Ph.D.... However, after participating in research this summer, I am pretty sure that is not what I want to do for the rest of my life. ... I really love school... So I see no reason why not to pursue a masters..."
Career Plans	3: not certain what path will be "Every aspect of meteorology interests me..."	2: not research "I don't feel that research, the way I did it this summer, is for me."
See Self as Scientist	4:"I do think of myself... [but] since I have never done any research, I could envision my answer to this question changing."	2: no "I am a person who likes to apply knowledge generated by others, not come up with the knowledge myself."
Scientist Description	- smart - hard working - insightful - helpful - friendly - visionary - questioning - like ordinary people - maybe a little crazy	- passionate - hard-working - laid-back - friendly - motivated - smart - micromanagers

Table 5. Summary of pre- and post-program survey Likert score responses and explanations for Dave.

parents have master's degrees and have been frustrated and limited in their careers. She likes school "a lot" and thinks she will like research because it involves working through things and figuring things out. She has captured two process elements of research, which may be a sign of maturity in understanding.

Summary of post-REU career ideas - Ann liked her project and relationship with her mentor. She was fairly independent and it suited her well. She liked the nature of research, specifically the programming she did. The exposure to graduate students and graduate school was helpful. She noted that although her school has a Ph.D. program in her major, those students are separated on a different part of campus. Her career plans may be slightly stronger, though her Likert score went down. She cannot see beyond simply going to graduate school but she left the program thinking a particular subject might be interesting to pursue in graduate school and finding that subject seemed to make her feel better.

After the AMS meeting, Ann was "very excited" about all the people she spoke with about graduate school and careers, including scientists working in a research area not found at her home institution or in Norman, Oklahoma.

Changes - She still likes research and hasn't changed her opinion very much. The nature of research didn't change but her description of scientists added more human qualities. Ann said attending the professional conference gave her opportunity to talk with people who could provide direction to research areas she found interesting.

Dave

Summary of pre-REU career ideas - As he came into the program, Dave was very optimistic about pursuing a Ph.D. in meteorology. His conviction about a Ph.D. revolved around his interest in teaching: "...to become a professor, you need a Ph.D." Despite his answer to the graduate school question, he is not clear about career direction, stating he had been interested in forecasting in high school but "then [he] went to college, [and] was exposed to many other facets of meteorology" and

discovered that "every aspect of meteorology" fascinated him. He appears to have high self-efficacy regarding being a scientist, saying "I like hard work, I like to discover things, and I like education, which are things that I believe all research scientists embody."

Summary of post-REU career ideas - Dave did not enjoy his research project. He wonders if this is because he does not like research or because his project did not interest him. He would have preferred studying synoptic scale weather. He states he would have preferred answering the question "why" rather than "fiddle around with numbers." He enjoyed the final write-up and presentation, at which he excelled.

After doing research Dave is "pretty sure" pursuing a Ph.D. is not what he wants to do. He continues to assert his love for school and states he would still pursue a master's degree. As far as careers, he has no well-defined plans and would consider many different careers. He was planning to keep an open mind, stating, "It might be one of those things when the perfect job opportunity comes up, I will know and seize the moment."

The summer helped him focus his ideas on careers though he has no specific one in mind. He found he enjoyed communicating weather and science, his passions and hobbies, so he would like a career where he can do those, such as broadcast meteorology, teaching, or science writing.

Attending the AMS Annual Meeting several months after the program appeared to change Dave's outlook on research. After returning he wrote that he was now "compelled to work on" several interesting projects after talking with a leading scientist about areas "ripe for further research" on snowstorms. He wrote, "Attending [the meeting] had a profound impact on me and likely will alter my future career and educational path."

Changes - Most notable was Dave's dislike of his REU research project, which resulted in him changing his career aspirations by the end of the program. His career plans shifted back toward research after attending the professional conference.

DISCUSSION

The only statistically significant difference before and after the REU experience was detected in students' plans for graduate school. The undergraduate experience seemed to reinforce an already high desire to continue graduate studies, especially because they recognize that most of the mentors and forecasters have graduate degrees. It is also possible that, as they did research, they recognized that the meteorology knowledge obtained less than a year from graduation would probably not be enough to understand the details of meteorology, such as computer models and complex interaction within the atmosphere.

The non-significant results related to well-defined career plans are interesting. Several students mentioned being overwhelmed by the number of possible career options within meteorology they discovered through the summer. On one hand, it could be that a student with a career in mind before the REU program will reconsider as he or she meets more meteorologists, attends seminars, and completes his or her research. On the other hand, students without a career in mind before the summer will leave without a decision, precisely for the same reason. We did not see the students frustrated or unhappy about their careers. They were excited about recently-discovered opportunities that were highly compatible with their interests. We called this phenomena "happy confusion." Rogers (2003) talked about a similar aspect to the diffusion of innovations, namely that complexity in a new idea tends to delay adoption or acceptance of that idea.

The other non-significant result was related to students' perceptions of becoming scientists. Because most of the students did not have research experience, the REU program might have served as a way to show students how research is really done. This might have shattered some of the students' idealized visions of scientific research and discouraged them from considering research as a career option. Conversely, those realities might have "hooked" those students who were not sure what to think about research. A quick look at the qualitative data suggests that students mentioned positive aspects of their research experience, such as the opportunity for some students to choose their projects, the amount of declarative and procedural knowledge learned, the independence of thought developed, the skill in expecting the unexpected from research, and the feeling of accomplishment when an important result is found. Students also lived the negative aspects of scientific research, such as the social isolation as hours are expended working with a computer, the monotony of large-scale data entry, the feeling that there are so many variables and parameters in continuous interaction there is no way to control for all foreign variables, the lack of focus as their attention shifts from one sub-problem to the next or one sub-routine to the next, and the lack of self-motivation or guidance when the mentor gives the student too much independence.

Overall, the REU program attempts to provide the most realistic research experience possible. Although one of the goals of a program like this is to attract qualified students into research, if the students' experiences help them clarify their goals with respect to being a researcher either way, the program has met an important objective.

Some interesting themes can be identified from the full set of qualitative data. For example, several students mentioned the fact that they felt that their effort, knowledge, and research were valued by their peers. Another important aspect that several students mentioned was the benefit of attending and presenting at a professional meteorology conference, such as the AMS. Several students were impressed at the number of professional meteorologists that stopped at their poster to talk to them about their project. Others pointed out the networking opportunities and graduate school orientations that are common in such a meeting. Students also mentioned the fact that by attending talks and reading posters they became aware of career options and sub-disciplines within meteorology they previously were unaware of.

Based on the students' comments, a few general recommendations for similar REU programs are inferred:

- If possible, have the student choose his or her own project before arriving at the research site. Few students had this opportunity, and spent a summer doing research in an area that was not as interesting for them as they had expected.
- Require students to attend at least one national professional conference and provide funding for it.

Students might not have been able to attend a national convention and present their results if not for the NSF travel support.
- If it is possible for a student to choose between a talk or poster, the REU students overwhelmingly suggest the poster. It provides the opportunity for a less intimidating one-on-one dialogue, which works fine for those students who are anxious about talking in public.
- Inform students about the realities of scientific research. Some students expect the research plan to flow flawlessly and to obtain important results in about ten weeks. However, reality might be different: an analysis might have to be redone, a dataset might not be available, an instrument was not working properly and the data is useless, or the weather might not cooperate.
- The mentor should be an approachable, supportive figure, carefully gauging the student's ability to work independently. The mentor must find a careful balance, guiding the student and allowing him or her to struggle a little in order to discover their capabilities.
- Projects must be designed to be feasible, focused problems, yet scaleable so as to allow some ability to deal with unforeseen problems given the tight time constraints.
- Make the summer a varied experience. Interlace research with seminars with field trips and social activities. Although some students preferred long stretches of uninterrupted research time, most feel that variety is the key for an interesting and not too stressful summer.

CONCLUSION

There is overwhelming evidence that REU programs are having a positive impact on students' decisions to pursue a career in science. An analysis of the evidence from the National Weather Center REU program supports this assertion. Since the late 1980s the National Weather Center has contributed to this area by providing meteorology students an opportunity to do research, attend seminars, and visit many of our facilities in Norman, Oklahoma. Evaluation data provided by the students suggests that they leave the program with a more certain idea about attending graduate school.

It was also found that the research experience provides students a wealth of information about career options, causing them to modify their career plans or providing more options for those students who remain unsure of a science career. There is no doubt that career clarification towards meteorology careers is going on, which is a positive impact of the program. In addition, the fact that the research experience is as real as possible shows students both the positive and not so positive aspect of scientific research. The data supports the notion that some students become more interested in science after their experience, while others might realize research was not what they thought. In either case, the clarification of what research involves is definitely occurring, which is a positive impact of the program. Although the quantitative data seems to suggest that the REU program has no effect on career choice or whether students see themselves as scientists, the qualitative data provides a rich context that strongly supports the notion that the NWC REU program is having a positive impact on students.

As always, research findings should be examined carefully for limitations. In our case, several limitations are apparent. First, our participants are not selected randomly, so self-selection might create a biasing problem. Second, it is possible that some students might have not been honest in their evaluation, providing positive responses to please the REU program director. Third, the use of survey questionnaires instead of interviews prevented the researchers from asking follow up or clarification questions that would have provided more contexts on the students' experiences throughout the summer. Fourth, the surveys were carefully constructed but were not validated by other subject matter experts. Fifth, due to limited sample size, non-parametric tests were used, although it is well known they might not be as powerful as parametric ones. Overall, we think that the data were clear enough to suggest a positive impact of the program, which is consistent with evaluations from other REU programs, as referred to in the introduction.

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