THE EDUCATIONAL FUNCTION OF AN ASTRONOMY REU PROGRAM AS DESCRIBED BY PARTICIPATING WOMEN

by

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For Tim.

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ABSTRACT

The long-running REU-program is tacitly intended to increase retention and provide "an important educational experience" for undergraduates, particularly women, minorities and underrepresented groups. This longitudinal, two-stage study was designed to explore the ways in which REUs acted as educational experiences for 51 women in the field of astronomy, in an attempt to develop a theory of experience related to the REU. Stage-1 consisted of an *ex post facto* analysis of data collected over 8 years, including multiple interviews with each participant during their REU, annual open-ended alumni surveys, faculty interviews, and extensive field notes. All data were analyzed using a theoretical framework of continuity and interaction, in a search for transformative experiences. Four findings emerged, related to developing understandings of the nature of professional scientific work, the scientific process, the culture of academia, and an understanding of the "self." Analysis provided an initial theory that was used to design the Stage-2 interview protocol. In Stage-2, over 10 hours of interviews were conducted with 8 participants selected for their potential to disconfirm the initial theory. Results indicate that the REU provided a limited impact in terms of participants' knowledge of professional astronomy as a largely computer-based endeavor. The REU did not provide a substantive educational experience related to the nature of scientific work, the scientific process, the culture of academia, participants' conceptions about themselves as situated in science, or other aspects of the "self." Instead, the data suggests that these women began the REU with pre-existing and remarkably strong conceptions in these areas, and that the REU did not function to alter those states. These conceptions

were frequently associated with other mentors/scientist interactions, from middle school into the undergraduate years. Instructors and family members also served as crucial forces in shaping highly developed, stable science identities. Sustained relationships with mentors were particularly transformational. These findings motivate an ongoing research agenda of long-term mentoring relationships for women in the sciences, at a variety of stages and across multiple disciplines.

CHAPTER 1: INTRODUCTION

> Any theory and set of practices is dogmatic which is not based upon critical examination of its own underlying principles. (Dewey 1938/1997)

Introduction

More than one hundred years ago, John Dewey and others of the Progressive Movement in education, saw that the informal opportunities of public school students were insufficient to provide the breadth of experiences required to prepare them for the many tasks demanded of a useful citizen. The Progressives suggested that a variety of formal educational experiences would benefit students, and perhaps, compensate for this shortfall. In a similar way, today's stakeholders in science, technology, engineering and mathematics (STEM) have asserted that traditional classroom-based practices are insufficient to adequately prepare the next generation of STEM practitioners and citizens. They have sought to provide students with the additional experiences that they might need to develop their interests and abilities in the various STEM fields. As part of the total education of students, science faculty and other interested parties have operated under the tacit assumption that undergraduate students studying STEM derive many benefits from participating in undergraduate research experiences. For these students, many faculty hope that participation will enculturate students into the scientific enterprise, help students develop a sense of belonging to the larger scientific community, and teach students important laboratory and analysis skills not easily taught in the lecture classroom. In addition, it is thought that participation in research experiences will encourage students to persevere in what is frequently thought of as a leaky "STEM pipeline," so that they can meaningfully contribute to the national scientific enterprise.

While this progressive approach to the education of STEM students is undertaken with all good intention, as educators we are responsible for evaluating the nature and effectiveness of the experiences that we provide for students. As Dewey (1938/1997) argued: "The belief that a genuine education comes about through experience does not mean that all experiences are genuinely or equally educative. Experience and education cannot be directly equated to each other" (p. 13). However, in the case of many research opportunities for undergraduates, the widespread agreement regarding the importance of these experiences is rarely questioned despite the fact that there has been little systematic educational research attempting to uncover the true impact of an undergraduate research experience (Guterman 2007). This deficit in supporting or even guiding, educational research in the science education literature has not deterred scientists or policy makers from urging the STEM community to participate in creating and supporting undergraduate research programs. In many ways, the usefulness of the undergraduate research experience has become the very kind of dogmatic reform that Dewey warned of over one hundred years ago. Given the importance of producing a well-educated STEM workforce and populace, we are compelled to investigate the nature of these experiences for undergraduates through a variety of means, in a variety of contexts. The purpose of this study was to gain insight into the impact of these experiences by investigating the case of a specific group in a single context: women who participated as astronomy undergraduates in a Research Experiences for Undergraduates (REU) program, over an eight year period.

The Research Experiences for Undergraduates (REU) Program

Perhaps the most well known call to action for colleges and universities to provide research experiences for undergraduates comes from a 1998 Carnegie report, *The Boyer Commission on Educating Undergraduates in the Research University—Reinventing Undergraduate Education: A Blueprint for America's Research Universities* (Boyer 1998). Known widely as "Boyer-2," this report aggressively challenges all universities to make research-based learning the standard for undergraduate teaching. The underlying rationale for this call is that the graduate and research programs of American universities have immense fiscal and human capital resources which could be applied to improve undergraduate education. The authors persuasively argue that although American universities can provide the best graduate education in the world, this rarely translates to outstanding undergraduate education. Countless undergraduates rarely ever see the world-famous professors their institution's advertising brochures tout. They further propose that productive researchers could benefit by finding new stimulation and creativity when interacting with eager and imaginative undergraduate students.

In this context, research-based learning is defined as, "an inquiry or investigation conducted by an undergraduate that makes an original intellectual or creative contribution to the discipline" (Wenzel 1997, p. 17). Many major science funding sponsors have responded to Boyer-2 by developing or enlarging programs in support of undergraduate research. These sponsors, including the National Science Foundation (NSF), National Institute of Health (NIH), National Aeronautics and Space Administration (NASA) and the Howard Hughes Medical Institute (HHMI), have programs to support research experiences and opportunities for undergraduates. In these programs a typical participant could expect to spend ten weeks during the summer, engaging in research under the supervision of a mentor in their field, at a facility other than their home institution.

The National Science Foundation's *Research Experiences for Undergraduates* (REU) Program was initiated in the early 1980s as an extension of the NSF-funded Undergraduate Research Program (URP) from the 1970s. Its early goals were to provide opportunities for high caliber undergraduate students to participate in summer research experiences at national laboratories and observatories (Wright 1996). In the late 1980s, the program was expanded to provide support for students to work at large research universities. In recent years, the program has begun to focus on providing access not just for the top students at large universities, but also to students at smaller liberal arts institutions, with a particular emphasis on providing pathways into STEM for women and underrepresented minorities. The purposes of the programs have not changed over time, with the exception of expanding the demographics of students targeted. As described in the REU program solicitation for 2009, the NSF REU program intends to "involve students in meaningful ways in ongoing research programs or in research projects specifically designed for the REU program" (p. 2). Its aim is to "provide appropriate and valuable educational experiences for undergraduate students through participation in research" (p. 4).

To give a rough idea of the footprint of the program involved in this study, and to illustrate the extent of the resources committed, in 2010 the NSF REU program expected to operate at a level of investment in excess of $67M, at nearly 2,000 sites and, if the pattern of previous years continues, it would support over 4,500 undergraduates across a wide array of STEM disciplines (NSF 2009). Given that approximately 120,000 students earn undergraduate degrees in STEM disciplines each year (National Science Board 2004), NSF's REU program funds experiences for roughly 4% of each year's STEM graduates, at a dollar figure near $13,000 per student, per summer.

Clearly, the REU program serves a relatively small population of undergraduates, in terms of overall numbers, and as a proportion of the total number of STEM undergraduates. This program occurs over a relatively short period in the whole of the undergraduate education (10-12 weeks over the summer at a location geographically distant from the student's undergraduate institution), and represents a substantial use of scarce resources. As an issue of public policy there is significant reason to search for support for such an investment.

According to the NSF (2009) REU solicitation "the REU program is a major contributor to the NSF goal of developing a diverse, internationally competitive, and globally-engaged science and engineering workforce." This is done, presumably through the previously stated goals of retaining and appropriately educating potential members of the STEM workforce. If there were sufficient evidence to support this assertion, it would provide warrant for the large expenditure of resources associated with the REU program. From the viewpoint of educational research there is reason to explore questions related to the validity of the program's untested, underlying assumptions. Evidence that REUs and REU-like programs fulfill an important role in retaining women, minorities and disabled persons in the field of academic science, or that they serve an essential educational function in the preparation of the STEM academy, would provide educational researchers with a success story that they could explore, analyze and hopefully replicate in other contexts. Educators have searched for a means of enculturating women and other underrepresented groups into STEM, for decades. If the NSF REU program is truly a major contributor to the cultivation and education of these groups, it is worth understanding at the level of its underlying mechanisms.

Arguing for the Participation of Women in STEM

Historically there is ample reason to be concerned about the participation of certain populations in academic STEM. The participation of women, the population of concern in this study, has been the topic of volumes of research literature. It is clear that as early as the mid-1950's, serious discussions about the participation of women in the STEM fields were beginning to occur. At that time, and into the early 1960's, convocations of concerned parties at institutions such as Radcliffe College, the Massachusetts Institute of Technology, and the New York Academy of Science, began to define the parameters and explore the nature of a phenomenon that many were beginning to view as a looming problem (Sonnert 1999).

Following from the work of Selby (1997) and Sonnert (1999) there are at least three arguments traditionally advanced for purposefully increasing the number women in the academic STEM fields. First, the equity argument suggests that the unfairness of possible gender discrimination should be a topic of fundamental concern, as equity is a key value of our society. In response to this argument, policy and legal measures, most notably Title IX legislation in the 1960's and 1970's, made possible a remarkable increase in the number of women joining the science professions during the 1970's (Selby 1997). According to Sonnert (1999) the equity argument was sufficient to reduce the number of formal barriers to women's participation in STEM, but in moving toward true parity, this argument by itself has fallen short, and additional arguments are needed to bolster the equity concern. In other words, Sonnert asserts that simply arguing that "there should be more women in science" in and of itself was insufficient to motivate changes.

Secondly, the 1980's brought a concern in the area of human-resources, merging the concerns of those advocating for women in science and those advocating for America's global leadership in science. In 1990 NSF projected a serious shortfall of scientists, which alarmed those who considered a shrinking pool of scientists a sure recipe for national disaster. Tapping into the underrepresented pool of women (and minorities) was seen as a means of supplementing the traditional talent pool –the white male population- and also boosting the proportion of American scientists in the face of an influx of foreign nationals. The Science and Technology Act authorized in 1980 had already attempted to address this concern and specifically mandated that NSF take action to increase the participation of underrepresented groups in STEM. However, by the mid 1990's it seemed that the shortfall predictions were not going to come to pass (Tobias, Chubin & Aylesworth 1995). The workforce issue had become a much smaller concern, insufficient to support the argument in favor of women.

Recently, an argument more central to the practice of science has come to the forefront. There are several versions of this concern, but in brief, this argument states that diversity among scientists, including an increase in the number of women in the fields, is vital for the quality of science as a whole (Chubin & Malcom 1996, Wilson 1992). Some members of the scientific community assert that science is socially constructed and that the social makeup of those who engage in the enterprise influence the types of questions that are asked and the lenses through which those questions are investigated. The presence of a wider variety of scientists will increase the range of research topics and the hypotheses brought to investigations. Collective blind-spots may be more quickly investigated and thereby eliminated. In the end this argument may provide the most compelling reason for the scientific community to pursue parity in academic STEM fields.

The Presence of Women in the STEM Fields

In the volumes of literature addressing the issue of the participation of women in science, it becomes clear that the statistics related to gender parity in academic STEM are put forth as the motivation for research in the field and the many programs related to the parity effort. Clearly, in the early 1970's the data indicated an overwhelming predominance of males in the academic and workforce STEM fields. In 1973 only 8.7% of the doctorates in science and engineering were awarded to women (Babco 1997). In the recent literature in the field another statistic is cited to support the assertion that little has changed in the subsequent twenty years. According to Babco, only 21.6% of doctorates in STEM were awarded to women in 1995 (1997). The argument put forth states that, while this statistic demonstrates a doubling in the percentage of doctorates awarded to women, progress has been insufficient and action needs to be taken.

But when we look at the statistics being cited in the literature it becomes clear that there is a great deal of data recycling going on. An inspection of citations of gender and science related articles written since 2000, shows that many of these articles cite statistics from publications written in the 1990's. Many of those publications, in turn, cite motivational arguments and statistics from publications written in the 1980's. In addition, the citations ignore the non-linear pattern of the gender shift. A fresh look at the data collected on the demographics of the STEM fields is clearly needed. Recent data indicate that parity has been achieved in some fields, while others are near parity. Only a select few fields still show dramatic gender disparities: engineering, computer science and physics and astronomy. Furthermore, even the field of physics and astronomy appears to have made some improvement in the participation of women. According to the most recent large scale study of gender representation, there is little in the way of disproportionate attrition of women from the field, with the exception of the high school-college transition (American Institute of Physics 2005).

The same study indicated that much of the remaining disparity in the academic hierarchy of the field can be attributed to the time-lag involved in moving both men and women through the academic ranks. Time-lag has not been taken into account in many studies on the issue of women in the sciences. Many studies erroneously look at the current percentage of women who receive Bachelor's degrees in physics and astronomy, and conclude that an equal proportion of women should be represented at all subsequent levels. For instance, in 2003, 22% of Bachelor's degrees in physics were awarded to women, therefore, many assume that if the system is working, women should also constitute 22% of those who have attained the rank of Full Professor in Physics and Astronomy. These data are used to demonstrate the fabled "leaky pipeline." This point of view fails to note that those who were at the rank of Full Professor in 2003 would have earned their doctoral degrees approxiamately least twenty years earlier. In the period where 2003's Full Professors were earning their doctorate degrees, 1967-1980, only 4% of PhD's in physics and astronomy were awarded to women, which is a close match to the proportion of women who were Full Professors in 2003: 5%. This same pattern is seen at other junctures in the pipeline. Women who are now Associate Professors in physics and astronomy earned their degrees between 1984 and 1991, comprising 9% of the population. They now represent 11% of the Associate Professors. Assistant Professors matriculated between 1991 and 1997, representing 12% of the population then, and 16% of the population now. If anything, a consideration of time-lag indicates that there is not only a lack of leak in the pipeline at these stages, women are actually succeeding in the academy at slightly over the expected rate. Moreover, the increases seen in each doctoral group predate the emergence of research experience programs like the REU, suggesting that the REU and other similar programs cannot be credited with the increase in women in the STEM pipeline.

The Role of REUs in Retaining Stem Academics

While the trends toward parity could be considered to be encouraging, it begs the question, as to if the improvements in gender equity in the STEM fields could be attributed to any specific interventions, such as the REU program. Much of the data indicate that the greatest rate of change in the representation of women in STEM, predates the inception of these programs and that the rate of change slowed during the 1990's (Sharpe & Sonnert 1999). Specific studies related to the impact of REU programs on retention of women in the STEM fields. corroborate this finding. Studies by Seymour and her colleagues (2004), Lopatto (2004), and SRI International (2006) superficially indicate that REUs may have some impact on retention, but upon closer inspection of the data in these studies, one finds that the number of REU participants who decide to attend graduate studies in their field as a result of their REU experience, is very closely balanced by the number who decide not to attend graduate school in their field as a result of their REU experience, for a net zero effect. A 2003 review of the research literature and evaluation work concerning undergraduate research programs, indicated that several authors do indicate increased retention as a benefit of REUs, but that the majority of these studies are highly biased or methodologically flawed, and that their claims are rarely substantiated by data (Seymour, et al. 2004).

A subsequent qualitative study suggests that an REU experience in astronomy, regardless of the quality of the experience or the participant's affective response to the REU, has little impact on a woman's decision to attend graduate school in astronomy (Slater & Slater 2008). The author of this paper collaborated on that study, which attempted to describe relationships between the types of REU experiences women were having in the field of astronomy, with their subsequent retention in the field. An analysis was conducted using six years of archived interviews and field notes, which resulted in a failure to find such a relationship. Participants who retained in the field had both disappointing and pleasant REU experiences. Others left the field, with no discernible pattern found related to the nature of their REUs. Only after removing all data related to the REU itself, was any pattern found: participants closely followed the plans they had for graduate study prior to the REU. Out of 38 participants, only two changed their minds; one chose to try graduate studies in astronomy despite previous plans, and one chose another path despite initial leanings towards academic astronomy. This represents a 4% swing in either direct which resulted in a null total impact, a finding that agrees with Seymour and colleagues' 2004 study in which she also found 4% swings that cancelled out. Despite popular wisdom and the best of intentions, an inspection of empirical research on this topic provides little evidence to support the assumption that REU experiences have an impact on the retention of women in academic STEM.

The Role of REUs in Educating Stem Academics

These findings narrow the benefit of REU-like programs to one of educational outcomes, which served as the focus of this study. In moderately broad terms, an experience can be educational for an individual if the experience serves one or more of a variety of functions including: preparing an individual for a future role or function, training the individual to function in a social environment, helping to refine one's judgment, or acting to influence an individual's attitude or affective response to a stimulus. In broader terms a meaningful education experience can be considered to be transformational in nature, functioning to "develop the personality of the individual and the significance of his life to himself and to others" (Kirk, as cited in Johnson 1968, p. 17). If REUs function in an educationally significant manner, as intended, they are not only serving to improve the quality of the academics in STEM, they are serving to improve the lives of the women who participate in the programs.

Prior Research Related to the Educational Nature of REUs

This question has been indirectly addressed, from certain perspectives, by a variety of researchers. Seymour and colleagues evaluated and summarized much of this work and found that the majority of published scholarly work and program evaluation suffered from methodological weaknesses, and that most claims were weakly supported by data (2004). According to the authors, much of the work published on the impacts of research experiences for undergraduates, is promotional or descriptive in nature, in which no evaluation or research evidence is offered. Other weaknesses included incomplete descriptions of programs and research designs, inferences made from anecdotes rather than data, and a lack of validation of instruments used in data collection. Of the literature reviewed, there are few publications that do demonstrate reasonably sound methodologies and data-based claims, and these offer little insight.

There are a few cases in which high quality, scholarly work supports the notion that there are suggestions of educational benefits from undergraduate research experiences. A few of these more promising studies find there to be some meaningful educational impact for undergraduates (Kardash 2000, Ryder, Leach, & Driver 1999, Rauckhorst 2001). These studies all involved research experiences that occurred over many months during the academic school year at students' home institutions. Therefore, the context is sufficiently different from the traditional 10 week summer program as to merit questions of transfer of findings. Other studies (Lopatto 2004, Seymour et. al. 2004) sought to "determine an empirically established set of benefits generated by undergraduate research experiences." Findings from these studies may not speak to the experiences of women in disparate fields such as astronomy, as the number of women included was low, and the data were aggregated across all fields. As disparity varies across fields, the educational value of the REU may vary as well. More importantly, these studies relied upon Likert-type scales which may or may not accurately represent the opinions of the women involved in the studies, as some researchers have raised questions regarding the validity of forced choice instruments in studies involving females and complex topics (Brown & Gilligan 1992, Grant & Harding 1987, and Holden & Edwards 1987). [1]

Clearly, there is a great deal to learn about research experiences for undergraduates, particularly those of short duration. Due to the contexts studied and the methodological issues put to use in prior studies, findings do not yet address the experiences of females in the most stubbornly disparate domains, such as astronomy. More importantly, none of these studies have addressed the issue of research experiences' impacts, from a position grounded in the literature in women's academic experiences in science. This vast body of literature asserts that women make academic decisions for highly complex reasons (Eccles 1986) and that women engage in the sciences in a manner that is highly dependent upon social relationships (Baker 1995).

[1] In cases where cited literature used the term "female" or "females" rather than "woman" or "women," that language has been retained.

Description of the Study

This study intended to examine the nature, or impact, of REUs through a different research lens from that previously described in the literature. The most commonly published papers are written through an "evaluator's lens," where programs report that students state, on end-of-summer exit surveys, that they enjoyed their summer experience and benefited from it. In contrast, the research in this study adopted a perspective of asking REU alumni, many years after their graduation, which learning experiences most influenced their development within the STEM field, in order to ascertain where the REU might fit into the larger landscape of educational experiences. Hopefully, this new approach has lead to new insights, and has contributed to a better understanding of the educational function of research experiences for women, specifically in astronomy. For the purposes of this study the concept of an "educational experience" was broadly defined in the transformational terms discussed previously. The intention was to allow data collection and analysis to proceed in an open manner, to accept a wide variety of educational benefits, and to consider many factors as potential vectors for educational growth. With this perspective, it is hoped that the results of this study do not serve to merely define a set of potential educational benefits, but to also serve to explore the interior of the "black box" investigated in previous studies.

Therefore, this study is driven by one research question, which may be defined in two parts:

What were the experiences of women in astronomy REUs, and what educational role does the REU play in their development?

(1) In what ways does the REU serve to interact with the continuum of participants' other life and educational experiences? Is the REU serving to provide educational experiences that reinforce previous learning, or does it make a unique contribution? How does the REU experience situate within the larger context of participants' experiences? What is the magnitude of the educational power of the REU, as situated within the larger field of participants' other educational experiences?

(2) In what ways, if any, does the REU function as a transformative educational experience? In what ways does it change the ways in which these women think about the work of science and astronomy? In what ways, if any, do REUs change the ways in which these women think about themselves, in relation to the field of astronomy, the work of science, or in terms of their knowledge of self?

This study proceeded in an interpretive manner (Erickson 1986) working in a grounded theory model (Creswell 1998). Data collection and analysis focused on the meaning of the astronomy REU experience for women who participated as undergraduates, with the intention of developing a theory, or "a plausible relationship among the concepts" related to the research questions (Strauss & Corbin 1994). The methodology proceeded in two stages. First, a search was conducted on over 668 different pieces of archived interview data which had already been collected from 51 women who participated, over an eight year period, at an astronomy REU program. These data were reduced to themed findings in order to construct an initial theory. The second stage, served as a test of the initial theory. Interviews were conducted with a purposefully chosen group of participants, in an effort to search out confirming and disconfirming cases.

Organization of the Dissertation

Chapter 1 of this dissertation has provided a motivation for and description of the dissertation. In Chapter 2, a summary of research related to REUs and women's educational experiences in science will be described. Chapter 3 will detail the methods used in this study, and the results will be presented in Chapter 4. Chapter 5 will describe interpretations of the results, will attempt to relate these results to the larger body of literature on this topic, and will describe implications for future study.

CHAPTER 2: A REVIEW OF THE LITERATURE

Overview

This chapter briefly reviews the existing literature most closely related to developing an understanding of how undergraduate research experiences may serve as educational experiences for women in astronomy. This literature review focuses on three areas of scholarship. The first considers what is commonly known as the scientific career "leaky pipeline" pathway, and the rationale for considering the issue of educational experiences for females/women as being of particular interest in the sciences. Although there was no *a priori* assumption that the results of this study would involve a relationship between the educational experience and gender or sex, this section includes a brief discussion of the issue of gender and sex in educational research. The second section considers the nature of experience as it impacts education. This literature helps us to consider that all experience is not automatically educational in nature, and that the nature of the educational impact is highly personal to the participant. The final section of this chapter addresses the methods of and conclusions from previous research related to typical REU-like, summer research experiences.

Women in Science

The Leaky Pipeline

There is a great deal of extant literature related to the issue of the STEM career pathway "leaky pipeline." For decades the fields in STEM have used the image of a pipeline as a metaphor when communicating about the protracted and difficult processes that individuals must complete in order to become a professional scientist. The individuals who proceed through that process are the metaphorical fluid that passes through the pipeline. This pipeline is commonly known to "leak," by which we mean that many individuals drop out of the process, which is generally judged by those who have chosen a career in STEM, as a negative event. Just as the odds of a fluid leaking into a pipe are poor, few individuals re-enter the process of becoming a scientist, particularly after high school (Civian, et al. 1997). This would suggest that, in order for the REU to impact any women who was not already destined for a successful career in science, it must provide a powerful educational experience, from the perspective of its participants, and must do so for those who are in danger of "leaking" out of the STEM pipeline.

The importance of engaging women in science

One might ask why there is concern about the presence of women in astronomy. According to Sonnert (1999) there are three reasons why stakeholders, such as members of the scientific community and U.S. citizens, should be concerned about the preparation of women in the STEM fields. First and foremost, we should be concerned about parity as an equity issue. If it's true that women are choosing not to participate in science and are making that decision without the influence of barriers or undue challenges, then they certainly are entitled to freely make that choice. If on the other hand, these choices are being made in light of gender inequity, then we must address the issue as a matter of principle. As a Western civilization that values equity as one of our key social values, we can do nothing else.

In the past, a second rationale for valuing the participation of women in the sciences related to the human resources needs of our nation. In the 1980's, projections of the National Science Foundation indicated that there would be a serious shortfall of scientists, a subsequent thinning of the science sector and eminent national decline (as cited by Sonnert 1999). This human resources argument led to many programs intended to encourage the retention of women, and minorities overall, in science and engineering. While this projected shortfall is now doubtful (Tobias, Chubin & Aylesworth 1995) the panic has left us with a residual notion that a healthy supply of scientist in the pipeline is important for the nation.

Finally, from the point of view of the sciences, there is the notion that a diversity of participants will promote the quality of the scientific endeavor, from two directions. First, a more diverse population may choose to investigate a wider variety of topics. Secondly, a heterogeneous research community may be better equipped to recognize and eliminate blind spots extant in the research base. Two frequently cited examples of this phenomenon come from the field of biology in which Jane Goodall and Dian Fossey are noted for transforming the field of primatology by approaching theories of social dominance with a feminine frame of reference. While the notion that men and women may do science somewhat differently has received some acceptance in the life sciences (Fedigan 2008), the idea has largely been rejected in physics and astronomy (Traweek 1992). The reasoning used is summarized by Gregory (1988) in his assertion that "physics is primarily procedural. Its procedure is to uncover the value of a theory by determining its consequences and then seeing if these predictions are confirmed by measurements" (p. 187). The viewpoint that diversity in the physical sciences is good for scientific progress does not dispute his assertion. Instead, it points out that this process is not exclusive to the physical sciences, and that there is more to science than a clinical and objective process. It is as astronomer Maria Mitchell pointed out: "We especially need imagination in science. It is not all mathematics, nor all logic, but is somewhat beauty and poetry" (Gormley 2004, p. 84). While imagination, beauty and poetry are certainly not the sole domain of women, anymore than mathematics and logic are the domain of men, there is a tacit societal agreement that individuals along the gender identity spectrum, bring a variety of abilities, values, and insights to any task. This perspective can be summarized as promoting that a greater diversity in the pool of scientists will bring a greater diversity of these traits to the field, which can only be of benefit.

The Issue of Gender and Sex

In considering the knowledge base on the ways in which women, from young girls to women in the academy engage with and learn science, and the ways in which REUs may be educational experiences for women in a particular discipline, it is necessary to briefly consider the emerging work related to sex, gender and the implications of those distinctions on research related to the science learning. According to Glaser and Smith (2008), the term *gender* is frequently used to when discussing issues related to being male or female, and that these issues are actually related to *sex*, rather than gender. They assert that the terms are used as contemporary synonyms, and that most researchers fail to define the ways in which they use the terms within their work. The issues related to the ways in which these terms are used socially and empirically are, as of yet, confounded. Moreover, this study was not conceived as a study of wither gender or sex, and was strictly intended to conceptualize a theory related to the experiences of a given population of interest. No attempt was made to tease out the factors of the experience as it relates to being female, as different from the aspects related to being a woman. Given that neither gender nor sex are dichotomous constructs in which the categories are defined by differences that are absolute, and that the audience reading this study likely possesses robust prior conceptions of these categories, this study takes a pragmatic approach to this issue. In the reporting and discussion of results from this study, participants are referred to as women, and were asked to define their own status as either a man or woman. All participants who self-identified as a woman were eligible for participation in this study.

The Experience of Women in Learning Science Prior to and Subsequent to the Post-baccalaureate Transition to Graduate Studies

Central to gaining insight into how women engage in the pathway to becoming a scientist is understanding the nature of women's experiences in science education before entering graduate traineeships. This study intends to probe, in particular, the impact of transformative experiences and events at the transition point at the end of undergraduate schooling. One might expect to see that the educational pathway at this juncture fit coherently into the much larger continuum of a woman's life. In this way, the existing research on the women's experience in science, prior to and subsequent to this juncture serves to influence this study's methodology and the lens through which results will be analyzed.

A great deal of literature exists on women's experiences in learning on the journey to becoming a professional scientist. Taken together, researchers engaging in understanding women in science have been able to provide a rich, and highly consistent story about women's experiences. From the early years to the years in which a persisting woman finishes her career in the academic study of astronomy there are consistent results indicating that women distance themselves from, and perhaps even feel disconnected from, the traditionally male-dominated science career pathways. Several decades ago, researchers Fox-Keller (1983) and Sjoberg and Imsen (1988) suggested that women prefer to engage in science where can be feel personally involved or connected. This seems to hold true even today, particularly for male dominated fields, such as astronomy, physics, and computer science. In the context of astronomy, this causes one to wonder if women naturally feel connected to distant stars and planets in the same way they do about community ecological or medical problems that confront them and their families.

Much of the work describing women in the pre-college science context has involved focusing on differences between experiences of women and men in classroom interactions. Most directly related to the present study, researchers have argued that young men tend to receive more praise than young women for similar academic performances, receive more critical feedback on performances and are encouraged to be more assertive in classroom interactions (Jones & Wheatley 1990, Kahle 1990, Tobin & Garnett 1987, Morse & Handley 1985). In much the same way, it is unclear if the nature of K-12 school science as it is most commonly taught has characteristics that capture women's interest or creativity. In one notable work of many, Gough (1992) provides substantive evidence that the most typical school-based science learning is all too often characterized by step-by-step verification activities. This is in direct conflict with the characteristics of scientific problems that capture women's interest-those that are ambiguous and have multiple-correct solutions as described by Carlone and Johnson (2007). The overall impact of these differences appears to be that during the K-12 years, women experience subtle drift away from traditionally defined academic science. Teachers and peers seem to strongly contribute to this process in subtle and not so subtle ways, such as calling more often on male students and choosing males to lead student groups (Weitzman 1984).

It also appears that women natural tend toward collaborative rather than competitive behaviors, which may be a disadvantage in STEM fields which are often characterized as being highly competitive. Researchers have consistently documented that women prefer cooperative learning to competitive or solo learning environments (Kahle 1990, Eccles 1989, Johnson & Johnson 1987). As the day to day work life of an astronomer is frequently noted as being largely solitary, the work by Collings and Smithers (1984) showing that women often prefer learn well in contexts rich in social interactions, implies there may be an inherent conflict for women pursuing education leading to a career in professional astronomy.

In later years of the educational pathway, higher education experiences often express themselves as an inhospitable environment for women interested in the pursuing careers in the sciences. It is well documented that peers and faculty contribute to an environment that can range from neglectful to openly hostile (Seymour 1995, Seymour & Hewitt 1997). One pivotal point to emphasize is that the first year of college seems to contain a particularly large leak in the STEM pipeline where women, even those of high aptitudes, leave the sciences in disproportionate numbers (Civian 1997, Tobias 1990). Findings of others researchers indicate that feedback, both positive and negative, from faculty members is a measurably important factor in a student's personal attachment to the sciences, particularly for female and minority students (*viz*. Komarovsky 2004, Pascarella & Terenzini 1991, Phelan 1979). These same authors note that the "encouragement" variable is particularly important for women in learning environments. At the same time other researchers report that women receive less encouragement than men. In a study of factors affecting the choice of majors, women at one research-extensive university reported that this lack of encouragement had been a serious problem for them (Manis et al. 1989). In the fields of astronomy and physics, one study found that women at research-extensive universities were significantly less likely than their peers to report that a faculty member had taken special and personal interest in their success (Frazier-Kouassi *et al.* 1992). In addition, the quality of relationships and extended interactions with faculty members may be an important factor in women's confidence in mathematics, a related academic discipline crucial to success in astronomy (Sax 1994). Relationships built on time spent together and collaborative work, that include encouragement of the student to engage in the larger landscape of the research problem, and which support the student's sense of safety in the uncertain landscape of research, are particularly influential in maintaining confidence in the sciences. Clearly, there exists a great potential for an important disconnect between factors that support women's attachment to the sciences, and astronomy in particular, and the culture that they are encountering in their undergraduate experiences.

Taken together, this voluminous body of literature describes important aspects and barriers, both imposed and natural, along the educational pathways women take toward becoming a professional scientist. If one can understand which events contribute most strongly to STEM career pathways, this work can contribute to the growing scholarly literature base describing women in science. This provides substantive motivation to studying the transformations occurring as a result of particular experiences and events along that pathway.

“Educational Experience”

A complete treatment of the theoretical and empirical ways in which the education research community conceives of *educational experiences* would require volumes of text, and is impractical to complete in this context. Therefore, this section is limited to considering some of the writings of the philosopher who is most closely associated with the idea of experience in education, John Dewey.

In *Education and Experience* (1938/1997) Dewey argues that educational experiences should have both a societal purpose and a purpose for the individual student. Educational experiences should therefore provide students with benefits that are immediately valuable and which better enable the students to contribute to society. The value of the experience is to be judged by the effect that experience has on the individual's present, their future, and the extent to which the individual is able to contribute to the greater whole.

At the time of his writings, perhaps as in the present time, stakeholders differed in their opinions of the types experiences that might be most effective in producing these outcomes, with traditionalist favoring relatively structured, disciplined, ordered, didactic instruction on one hand, and progressives supporting relatively unstructured, free, student-directed education. Dewey criticizes both camps, asserting that traditional education lacks a holistic understanding of students and tends to designs experiences overly focused on content rather than content and process. Progressive education, he argues, is too reactionary and takes a free approach without really knowing how or why that freedom of experience can be most useful in education. Dewey argues that in order to improve matters, educators must move beyond supporting a paradigm, to developing a theory of experience which requires that we first understand the nature of human experience.

Dewey's theory is that experience arises from the interaction of two principles: continuity and interaction. In this context, continuity implies that each experience a person has will influence his or her future, for better or for worse. Interaction refers to the situational influence on one's experience, meaning that one's present experience is a function of the interaction between one's past experiences and the present situation. For example, in the case of this study, the nature of the educational experience is intimately intertwined with the participants’ prior experiences, the summer camps, formal coursework, early mentor relationships and other factors that continue into and interact with the REU.

Dewey suggests that once we have a theory of experience, in this case a theoretical understanding of the educational experiences found in the REU, then educators can set about progressively organizing our programs in a way that it takes account of students' past experiences, and provides participants with access to additional, meaningful experiences, thereby expanding their likely contribution to society.

A Critique of the Current Research on REU Programs

The three largest studies on students in undergraduate research experiences looked at the benefits of the research experience for all students, aggregating data for genders, racial groups, fields of study, and ethnicities. All reported similar findings; undergraduates frequently reported that working on research projects or on research teams as undergraduates, had been valuable experiences that had increased their self confidence in regard to future STEM careers when strongly positive and supportive faculty mentorship have been in place. Elaine Seymour and her colleagues at the University of Colorado interviewed 76 undergraduate research students at four liberal-arts colleges, (Grinnell, Harvey Mudd, Hope, and Wellesley) as well as their mentors (Seymour, Hunter, Laursen & DeAntoni, 2004). As opposed to the single 8- to 10-week summer research experience in a distant location that are most typical in NSF-funded REU programs, the students in this study were engaged in long-term research experiences at their home institutions. Few negative or qualified assessments of their research experiences were present in the data. Such positive results may seem to be somewhat surprising. However, these data are rendered from a non-random sample. Students who have already decided a career in scientific research is not for them are most likely absent from this study, while those who participated are interested in research and have the wherewithal to find these programs and successfully engage in them. These data were collected shortly after the end of the program, increasing the likelihood that the data are biased by the euphoria students frequently feel at the end of any program. One cannot realistically ignore the pressures placed on rising seniors, in small departments with few faculty, from whom they may wish to obtain positive letters of recommendation for graduate school. Moreover, the experiences of the undergraduates reported see to have been based in extended experiences at their home institutions that are apparently quite unlike the traditional NSF-funded REU 10-week experience.

A second study was conducted with students, at graduation and several years post-graduation. Seymour and her colleagues reported that both students and mentors frequently described the greatest benefit of being involved in an undergraduate research project as an enculturation into “becoming a scientist” (Hunter, Laursen & Seymour 2007). However, they found that students and mentors frame this notion somewhat differently. Students think of “becoming a scientist” in terms of their own personal and intellectual development and they describe how they become better problem solvers, develop important research skills, and increase their confidence that they “have what it takes” to be a scientist. In contrast, mentors think of “becoming a scientist” in terms of becoming socialized into the scientific profession; that students get to see what scientists do “outside the classroom” including attending conferences and participating in the publications process. As these sorts of notions are largely absent in the student interviews, Seymour suggests that students are generally unaware that they are being socialized into professional practice through their participation in research. Moreover, there was no attempt in this study to determine the effect of the program relative to other educational experiences. Participants were specifically asked to provide examples of the ways in which the program benefitted them, a prompt that begs the question. Participants were asked to provide examples to support an assertion that they may or may not have made on their own. It is possible that the responses they provided were prompted by a desire to be polite, or by the human tendency to validate the work of those for whom they might feel a connection, rather than by a robust belief that the REU student experience had been of value.

Extending this research from an interview-based qualitative approach to a survey-based quantitative approach, David Lopatto (2004) asked more than 1,100 students from 40 colleges and universities to categorize the benefits of participating in undergraduate research. Eighty-three percent of his respondents who participated in undergraduate research indicated that they would go on to postgraduate education in the science. He reports that these students with plans for postgraduate education in STEM fields were able to identify significantly more benefits to participating in research than students who did not have such plans. These results may imply that students who have metacognitive insights which help them identify the benefits of participating in research, are more likely to go on to graduate school. Alternatively, Lopatto's research may have revealed that students with strong prior commitments to post-graduate STEM education, and those without such commitments may process undergraduate research experiences, even very similar experiences, in very different ways. This interpretation is supported by what may be his most telling finding: just 3.5% of students change their plans for graduate school as a result of their research experiences.

By far, the largest and most comprehensive, quantitative research conducted to date on the impacts of undergraduate research experiences has been compiled by Susan H. Russell and colleagues at SRI International. In 2003, they surveyed more than 8,000 undergraduates and mentors who had participated in NSF-sponsored summer undergraduate research programs and followed up with another survey of the same students in 2005 (Russell, Hancock & McCullough 2007). As a comparison group, they further surveyed about 3,400 who had not participated in NSF-sponsored research programs, about half of which had participated in no undergraduate research at all. SRI disaggregated the results of undergraduate researchers who were working at their home institutions in longer-term projects from those at non-home institutions working in shorter-term, summer projects. At the end of the analysis the researchers report that their data did not indicate that one type of program was superior to the other, although the basis for this conclusion not addressed. This finding seems rather counterintuitive. One might suspect that the quality of the student/mentor relationship, which was earlier stated to be critical to success, would be improved when students and faculty have prolonged, day-to-day contact. One might further surmise that this enhanced relationship, in addition to a longer period of time to engage in their project would increase the likelihood that students would gain a richer understanding of the science content and processes related to their research work, yet neither of these effects are addressed in the SRI report.

Not surprisingly, SRI reported that most students who are involved in undergraduate research experiences are juniors and seniors with high grade-point-averages. Sixty percent of sponsored students reported that they had been interested in STEM "ever since I was a kid" with an additional 30% becoming interested in high school. Only 10% of sponsored students became committed to STEM after entering college. REU students overall demonstrate a strong, early expectation that they would pursue a Ph.D., with their expectations predating their entry to college and occurring at twice the rate of non-sponsored students. In addition, SRI found that students who participated in summer REUs were very likely to have participated in other types of research experiences, including year-long, home-institution projects, whereas the converse was not true. This finding confounds research results on impacts of summer REU programs for participants, and also raises the question of the need for such programs.

Russell and her colleagues report that undergraduate research programs have the greatest positive impacts when students are voluntary, rather than compulsory, participants in the culture of research. They find that students preferred programs where students choose "to participate because it seemed to be fun, [helps them with] gaining independence, attending conferences, understanding the "big picture," in contrast to programs in which creating "research proposals, reports, or poster presentations" are emphasized. As a result, they strongly suggest REU programs should "focus more on generating enthusiasm and involving undergraduates in the culture of research than on requiring them to complete specific research-related assignments" (Russell 2006). This recommendation is perhaps a bit unsettling, as the culture of research relies upon completing specific research related assignments. Further, this is a confusing conclusion to make, as REUs, by their nature, are voluntary experiences. In fact, they are competitive for admission. This also contradicts the SRIs own suggestion that students are learning about the research process as a result of their REU. If program directors follow SRI's advice, they will no longer provide the portions of the experience purported to be beneficial to the student. Overall, the SRI study suffers from unsupported assertions and logical inconsistencies.

These three studies are methodologically constructed in ways that warrant critical consideration. In both the Lopatto and SRI studies, data collected from participants is prescriptive. Both studies rely extensively on Likert-type scales, where students are asked to describe the nature of their REU experiences on a scale of one to five, on topics such as possible benefits of the REU, its impact on their future plans, and their level of satisfaction with the program. From a methodological approach, this type of data collection provides rather superficial information related to a topic that is highly personal and complex. For instance, where students were asked to describe their relationship with their REU mentor, such as in the SRI study, participants were only asked to provide the number of hours they interacted, with an assessment of whether this was "too little," "about the right amount," or "too much." No opportunity was provided to describe the nature of the interaction, or the mechanism by which this interaction may have been educational.

In addition to the poor match between the complex research questions being asked and the data collection method, these studies fail to report the data collected in a meaningful way, and fail to address issues of bias related to Likert-type surveys. There are substantial disadvantages to this approach. In the case of Lopatto's study, participants' responses to Likert-type items relating to educational benefits of the REU were reported as means, ranging from 4.13 out of 5 for "Understanding the research process," to 3.15 out of 5 for "Learning ethical behavior." These averages were reported without their standard deviation. This approach to data reporting is problematic for two reasons. First, the data were analyzed as interval, rather than ordinal data, without good reason for doing so explained in the paper. This is a dangerous practice, in that we cannot assume that the differences between adjacent levels are equal. As Jamieson (2004) points out: "The average of 'fair' and 'good' is not 'fair-and-a-half'; which is true even when one assigns integers to represent 'fair' and 'good'!" Second, the distributions of the responses are not provided, and cannot be discerned without the standard deviation. For example, studying a population of 20 participants, an average of 3.5 can be produced by 20 responses of "3" and 20 responses of "4." The same result can be produced by 25 participants providing a response of "5," and 5 participants providing responses of "1." Not only are these very different scenarios, but neither represents a normalized distribution, making the use of statistics such as the average and the t-test questionable. Given that the results of a Likert-type survey cannot be continuous, and can be subject to bias, the nature of the distribution is important.

Traditionally, Likert-type surveys often suffer from two types of bias that can account for the results as reported. First, there is acquiescence bias, in which non-hostile participants have a tendency to provide positive responses, particularly when in doubt (Weiksner 2008). Likert-type surveys are also subject to a central tendency bias, which suggests that participants tend to gravitate toward the most neutral response, in this case selecting a 3 on a 5-point scale (Bertram 2009). This bias is typically obviated by designing a scale with an equal number of positive and negative statements, but such an approach was not used in either of the Lopatto or SRI studies. Given these two types of bias, we should expect to see average scores that fall between 3 and 4, which matches the data reported in the studies. Without distribution data or supporting interview data, it is not clear whether the results of this study are a true result or a methodological artifact.

These methodological concerns are driving a move away from paper and pencil assessments and quantitative analysis in studies of women and science (Baker 1995). According to Baker, a shift toward more qualitative and contextualized methods is justified when one considers the differences in results between quantitative and qualitative studies. For instance, in a study conducted by Solomon and Harrison (1991) the researchers asked a group of students to engage with issues related to science education. Data were collected from individually completed questionnaires and from recordings of group discussions. The data from the questionnaires reflected many of the stereotypes expected in science education; the males provided fairly emphatic and decontextualized responses, while the females responded in more tentative, qualified ways. However, when the researchers analyzed the data from the group discussions, the differences nearly disappeared, with both the males and females engaging in contextualized, thoughtful discussion.

Other work by Baker (1990) and Baker, Leary, and Trammel (1992) also indicated that, when given the opportunity to participate in discussion, participants provided unexpected information. The common wisdom that females do not care for science, do not feel competent in the sciences, or feel marginalized in significant and pervasive ways, was unsubstantiated. Instead it seems that females enjoy science in much the same way that males do. Moreover, females are more like males than they are different, in terms of what science they would like to learn, and how they would like to learn it.

Other authors have suggested that forced-choice surveys are problematic when investigating complex, highly personal issues, particularly when researching females. In their review and subsequent study related to parenting surveys, Holden and Edwards (1989) found that the majority of mothers, 86%, were critical of the nature of the Likert-type survey, and considered it inappropriate for the subject matter. Chief among their concerns was that the survey items lacked context. Their response to any given question would depend upon the situation, with many participants indicating that they wanted to answer with "It depends" (p. 45). Nearly half of the participants indicated that some of the questions did not apply to them, but they were obliged to respond anyway, in which case many of them answered by mentally substituting similar situations. The analog for the present issue of REUs would be, that in cases where the question did not apply, women might substitute their thoughts related to similar situations, such as a home-institution research project, or a high school summer program. Other mothers in the study indicated that they struggled to "control their temptation to select the most socially desirable response" (p. 45).

Similarly, Grant and Harding (1987) assert that results from studies like the one conducted by the Girls and Technology Education (GATES) project raise questions about the predominant method, the Likert-type survey, used to investigate the relationship between females and science. In the GATES study (as cited in Grant & Harding 1987) boys and girls were asked to respond to Likert-type items related to their thoughts on science and technology. Data indicated that approximately 45% of girls responded in ways that were favorable to science, as indicated by choosing either a "4" or "5" on the scale, approximately 40% were neutral, as indicated by choosing a "3" on the scale, and 15% indicated a negative attitude toward science and technology by choosing a "1" or "2" on the scale. An investigation into the girls' reasoning related to the survey found that the girls who chose "3" on the scale did so because they were not sure of how to answer the question. When asked to explain their choice, participants indicated that they responded with the most neutral choice because: "It depends on what you mean," "It depends upon the circumstances," and "The (original) question didn't say which bit of science and technology you meant" (p. 339). The authors argue that females tend to consider and measure values embodied in science against "human values and aspirations" (p. 342), a complex construct that is not measured effectively using a Likert-type survey.

These studies indicate that the methodologies employed in much of the existing REU literature may be inappropriate. Forced-choice surveys conducted with the intention of finding the benefits of REUs have found such benefits, albeit with small impacts. None of the studies conducted thus far attempt to situate the experience in the larger framework of the participants' lives, and all of them proceed from the assumption that there are, in fact, positive educational benefits, an assumption that frames the research protocols, and which may beg the question.

The only large qualitative study on REUs was conducted by Hunter and colleagues (2007). In this study "interview protocols focused upon the nature, value and career consequences" of REU-type experiences (p. 42). During these interviews students were asked to describe the benefits from their REU-type experience, an interview prompt that asserts that the program provides benefits. Participants' descriptions were compared to a pre-defined checklist of expected educational gains. In the event that a participant did not mention one of the expected gains during the course of the interview, they were specifically asked about the unmentioned items. "All students were asked to expand on their answers, to highlight gains most significant to them, and to describe the sources of any benefits" (p. 42). Students were interviewed as "rising seniors," shortly before graduation, and again as graduates. Each time they were encouraged to describe the benefits of the REU-type experience.

Given the previously mentioned acquiescence bias, and the repeated request for descriptions of educational benefits, this protocol is poised to unintentionally present an enormous pressure for the participants to provide positive data. Data from this study reported that 91% of all statements referenced gains from their REU. As the researcher was persistently asking for data related to gains, this result was likely a foregone conclusion. It is impossible to know if the reported result is a product of truly meaningful educational experiences, or is simply an artifact of the protocol. It is reasonable to suggest that the protocol was heavily biased toward finding this result. Even so, the magnitudes of the educational benefits were small. The largest impact was seen in the area of "Personal-Professional" gains, a parent category that included disparate constructs such as increased confidence in the ability to do research, and gains in establishing collegial relationships. Even given the wide variety of potential benefits in this category, only twenty-five percent of students reported a gain in this area. All other benefits were reported at levels lower than 25%.

These results can be interpreted in a variety of ways. On one hand, we can state that the majority of sponsored student researchers stay in the STEM pipeline. This may indicate that these programs are essential for stemming the flow of talent, especially for women and minority talent, out of the STEM field. On the other hand, we might look at this same data and conclude that STEM career pipeline students are already well on their way to STEM careers, having decided long ago to pursue postgraduate degrees in science, and that undergraduate research programs make no measureable difference. In either event, the studies might indicate that REUs provide broad, meaningful educational experiences, particularly for women. If this is the case, the REU is accomplishing a feat that is unprecedented in science education, and doing so in just ten short weeks. A program of this nature requires investigation at the mechanism level, providing a deconstruction that can inform science education research and the larger group of stakeholders who are interested in the education of women in the sciences.

An alternative interpretation is that the existing studies have left much to be learned in this area. Additional investigations that employ appropriate data collection and analysis techniques, and that minimize bias through protocols, may support the common assumption that these are important educational experiences. On the other hand, such inquiry may indicate that previous findings are artifacts of the assumptions that prompted the research. As Dewey would assert, experiences can be, but are not necessarily, of educational benefit. Although it is commonly asserted that the REU is an important educational experience for women, the assertion has not been investigated from a framework that Dewey would agree with, a framework that considers continuity and interaction. This study addressed the question of the REU's educational benefit for women in astronomy, through a theoretical lens and methodology that probed for participants' unbiased meaning making related to the REU experience, as a continuation of other learnings that interacts with their larger educational experiences.

CHAPTER 3: METHODOLOGY

Introduction

This chapter describes the context and methodological approach to pursuing the research questions:

> What were the experiences of women in an astronomy REU, and what educational role did the REU play in their development?

(1) In what ways does the REU serve to interact with the continuum of participants' other life and educational experiences? Is the REU serving to provide educational experiences that reinforce previous learning or does it make a unique contribution? How does the REU experience situate within the larger context of participants' experiences? What is the magnitude of educational power of the REU experience, as situated within the larger field of participants' other educational experiences?

(2) In what ways, if any, does the REU function as an transformative educational experience? In what ways does it change the ways in which these women think about the work of science and astronomy? In what ways, if any, do REUs change the ways in which these women think about themselves, in relation to the field of astronomy, the work of science, or in terms of their knowledge of self?

For the purposes of this study, the concept of an "educational experience" is broadly defined in the transformational terms discussed in Chapter 2. The transformative action of the REU may be manifested in terms of participants' knowledge or understanding of science, their appreciation and value of the nature of science and the scientific enterprise as a human endeavor, and/or their understanding of themselves as being a part of, or separate from, the scientific enterprise overall. Further, the study will attempt to situate the REU within the background of previous and subsequent experiences, in an attempt to describe the relative magnitude of the REU as an educational experience. The relation of the REU experience to other life events is critical to the understanding of the behavior of the women involved; people's behavior becomes meaningful and understandable when placed in the context of their lives and the lives of those around them. Without that context, there is little possibility of exploring the meaning of the experience (Patton 1989).

This study was conducted in two stages. In the first stage, eight years of longitudinal archived data were analyzed *ex post facto*. In the second stage, interviews were conducted in an attempt to either refute or clarify findings from the first stage of analysis. Issues related to context and research relationships common to both stages will be described first. This will be followed by descriptions of the particular participants, data collection methods, and coding techniques relevant to each stage of the study.

Research Approach

This study takes an interpretive approach to questions related to the educational experiences of women in REUs. As described in Chapter 2, the work that has previously been published on the educational benefits of REUs has been conducted through positivist, quantitative methodologies. In this case, interpretive work was pursued in the belief that interpretive work may be better suited to the research questions, and in the hope of constructing a more powerful explanatory model. This position is consistent with that described by Erickson

In line with Erickson's position, it is important to note that the term "interpretive" is employed, instead of using the term "qualitative" to describe the research approach. Use of terms such a "qualitative" and "quantitative" can erroneously lead the reader to focus on data collection methods, rather than the philosophical approach taken in the study. "Qualitative" is often perceived to be that which is non-numerical in nature, even though qualitative work can use numerical analysis of a sort. Further, qualitative data can be employed in many legitimate studies that focus on external meanings, and are either positivist or behavioralist in orientation. For instance, in the case of these research questions, it would be possible for a researcher to collect qualitative data, such as interview and survey data, impose an externally derived coding system upon that data, and make meaning of the data from the expert, outsider perspective. In another instance, a positivist researcher might decide to approach the research questions by engaging in extensive fieldwork and copious, continuous narrative descriptions, producing exhaustive rich descriptions of the social setting. Although that work would rely upon qualitative data, it would be using that data from a non-interpretive approach. The use of the term "interpretive" indicates that the study is placing "central research interest in human meaning in social life and in its elucidation and exposition by the researcher" (Erickson, 1986) Interpretive research considers the local meanings of actions, as perceived from the point of view of the actors involved in the social setting. The difference between such work and the work of researchers operating from a behavioralist or positivist position is one of content and intent, rather than procedure (Erickson, 1986).

The interpretive approach is often employed in investigations similar to the one reported here. Interpretive research speaks to the nature of the social environment, the realization that treatments and programs are only part of the educational experience and the nature and content of the meaning making of the participants in the social environment. (Erickson 1986). This methodology is most useful when the researcher wants to know more about the specific structure of occurrences. In this case: "What is occurring in the education of these women engaging in an astronomy REU?" Interpretive work also assist in discerning the meaning making of participants, and how these events in this setting relate to happenings at other system levels: "What are the points of view of these women, as they progress through the REU? If we look at other aspects of their education, can that help us to better understand the educational nature of the REU?"

The answers to the research questions are neither obvious nor trivial. Although positivist research methodologies can lend some insight to aspects of these questions, they lack the ability to address the invisibility of everyday life. In the experiences of the REU program funders, the mentors, and the participants, an REU or REU-type program has become part of the university landscape. Because of its familiarity, and potential contradictions that relevant actors might not want to face, it is difficult to recognize patterns in the everyday business of the REU. According to Clyde Kluckhohn, "ordinarily we are unaware of the special lens through which we look at life. It would hardly be fish who discovered the existence of water" (1949, p.11). The connections that actors in this study might perceive, may or may not be accurate, and the accurate connections might not be obvious. This work, through its inherent reflectiveness, attempts to help the participants and the researcher to "make the familiar strange and interesting again" (Erickson, 1986).

The question of the educational nature of the REU for women is not trivial in that there is a need for specific understandings of the impact of concrete aspects of the experience. Answering the question, "Are women learning in the REU program?" with a general answer, such as "Yes," is not very useful. Other potential answers might be: "The participants each reported learning research skills," "Each participant is encouraged to give a presentation of their work at the end-of-summer colloquia," or "The participant was able to complete her data reduction project." These answers do not tell how the program used which techniques to educate participants. Without a closer inspection of the relationship between program features and outcomes, we cannot be sure of which aspects of the program are important, nor can we know how to transfer those important elements successfully to new situations. Interpretive fieldwork is an effective means to answer the questions in an adequately specific way.

Interpretive work is also a means by which to examine the social setting beyond superficial features, by providing local meaning. This may be especially important in the case of astronomy REUs. The NSF REU program has superficial similarities to other program, such as the Howard Hughes Medical Institute undergraduate research program. Within the REU program, astronomy REUs have surface similarities to programs in chemistry, and mathematics, among others. These similarities can be misleading, as events that seem the same may have very different meanings. For instance, both biology and astronomy REU participants may spend daily time "in the lab." However, work "in the lab" for the biology participant may consist of collaborative activity with other participants, graduate students and mentors. Work "in the lab" for the astronomy REU may mean solitary and stationary work in the computer lab, with headphones on in an attempt to avoid the distraction of interaction with other people who might be in the room. Studies beyond those conducted through a positivist lens are required to discern the important differences within, and between, the REU programs.

Another relevant use of interpretive methodologies involves considering that wider spheres may influence first order observations. Given the reality that enormous resources are allotted to REUs in the hope that they will educate, and influence of retention of women in the sciences, understanding the interplay between the program and outside factors, is crucial. Given in the importance of the goals, we must investigate the nature of these programs beyond superficial evaluations. For instance, in evaluation work it is common to make the observation, "The women who participated in our REU have all reported that they've found our program to be very valuable to them." This observation may be factually accurate; however, this observation does not include an interpretation that considers contextual factors. In the case of the astronomy REU in this study, participants routinely told their REU mentor, the program director and their mentor from their home faculty that the REU was “valuable” to them. At face value, it appears that participants are indicating that the REU was a meaningful educational experience. But, this statement could be interpreted quite differently depending on the presence of external circumstances and factors. If the participants’ career trajectories made it necessary to maintain deferential positioning in relationship to these other actors, the pressure to do so might outweigh the need to make a more honest evaluation known. For instance, rising juniors and seniors are most likely cognizant that they will be applying to graduate school within twelve months, and that those applications will require letters of recommendation. The need to have as many positive letters, from as many high profile astronomers, at as many institutions as possible, is an important contextual factor. It is reasonable to predict that some savvy women in astronomy may dissemble when directly asked, by certain parties, about their REU. At the same time, it is reasonable to assume that receiving positive feedback may serve the program and identity needs of mentors and directors. These actors have their own pressing contextual pressures. The positive feedback from participants provides relief from some of those pressures and discourages delving into the issue further. The result is that the combined contextual pressures of the parties may be fulfilled by an implicit social contract between participant and mentor, effectively cutting off the question: “In what ways is this REU functioning to educate the women who participated?" This is clearly an unsatisfying result. An interpretive approach is one means of shedding additional light on the inner-workings of the REU.

Finally, interpretive work is ideally suited to understanding the important meaning making of actors that are actually related to circumstances beyond the study site. According to Erickson (1986) there is a temptation on the part of instructors and researchers to think that what is happening in a setting is a result of that setting. In this case, it is tempting to believe that the education or later career success of women who have participated in an REU, is in some way related to the REU. If a large number of women who participated in the REU were to successfully move on to graduate studies, it would be satisfying to believe that the REU was a relevant factor. If many of the women who participated in the REU were noted to be high achievers in their careers, a correlational study would lead one to believe that the REU serves an important variable in the equation. This is the classic confusion of "correlation implying causation." An interpretive study may serve to describe the relationship between many factors, and either verifies a causal relationship with possible mechanisms, or it may serve to describe the nature of variables omitted from a more behavioralist or positivist study.

As this study is centrally concerned with the meaning that women have given to their REU experiences, and the linkage between that program and these participants' other experiences, an interpretive methodology is employed. This study intends to investigate beyond the obvious and trivial, describe issues of human meaning and choice, and develop knowledge that can be used for the improvement of educational practice. This work is "an attempt to be empirical without being positivist; to be rigorous and systematic in investigating the slippery phenomena of everyday interaction and its connection, through the medium of subjective meaning, to the wider social world." (Erickson, 1986)

Grounded Theory

The REU program is predicated upon the notion that these types of experiences are important for the retention and education of women, among others, in the STEM fields, including astronomy. As described in Chapter 2, previous research related to the educational benefits of REU has also been based upon the assumptions that REU are educational experiences, and that those benefits would fall within certain categories. Rather than resting upon a contextually situated theory, these studies have sprung forth, like the REU program itself, from *a priori* assumptions. Those assumptions influenced the nature of those studies, producing methodologies for which findings of an educational benefit were a foregone conclusion.

This study rests upon the notion that we do not know if the REU is of educational benefit. If it is of benefit, we do not know the nature of that benefit or benefits, and we do not know the mechanism by which those benefits occur. One way to understand the nature of the experience is to construct conceptual knowledge and explanation deductively from data related to the REU. This type of research is commonly known as grounded theory.

The modern construct of grounded theory is based upon the early work of Glaser and Strauss (1967) and the extensions of that work by Glaser, and Strauss and Corbin

(1990) among others. Although there are variations in the philosophy and methodologies employed in grounded theory, there is wide spread agreement that grounded theory is a general methodology for developing conceptual understanding or theory, which is grounded in data systematically gathered and analyzed. Grounded theory results in systematic statements of plausible relationships (Strauss & Corbin, 1994). The theory of relationships evolves through the research process, and does so through ongoing cycles of analysis and data collection. Although this kind of research can build upon existing theory, in the research process that theory must be constantly compared to the data generated.

Theory generated from grounded theory studies can aim at various levels, from high level general theory to smaller working hypotheses. This is a pragmatic study that aims toward developing a theoretical conceptualization (Strauss & Corbin, 1994) in which patterns of action and interaction among various agencies and actors are the primary concern. The concern is one of discovering the process by which women in astronomy are educated and the role that REUs may or may not play in that education. This is a fairly useful kind of research in that it intends to describe patterns of action and states of condition, either internal or external to the REU, that influence the astronomers' education. Awareness of that theoretical conceptualization then allows the reader to engage in prediction, in a limited sense: "*if* another situation occurs in which approximately similar conditions occur, *then* approximately similar consequences should occur." Where some forms of interpretive research do not make any claims of generalizability, grounded theory does.

There is a great deal of methodological flexibility within the grounded theory. The particular methodology employed in this study will be discussed in a later section, after discussion of context and research relationships and concerns.

Context

The REU Program and Participants

For more than two decades, the National Science Foundation has provided REU funding to institutions of higher education to run summer research programs for talented undergraduate science majors. This funding has occurred based on the assumptions stated in the NSF program solicitation: undergraduate research experiences are “one of the best avenues for attracting” and retaining talented students in science careers, and that they “provide appropriate and valuable educational experiences for undergraduate students through participation in research.” These awards are made competitively to institutions and are based loosely on the availability and depth of ongoing research programs that can include undergraduates and a mentoring plan which an institution promises to provide. In the field of astronomy, there are currently 14 participating institutions, each receiving approximately $10,000 per student participant per year plus an administrative fee of 25%.

The typical astronomy REU program hosts 8-12 advanced undergraduates for a 10-week summer research experience. REU program admissions are highly competitive both within and between programs, each program often receiving 100 applications for a limited number of slots. In an effort to meet NSF’s explicit expectations for supporting underrepresented students to pursue STEM careers, considerable attention is paid to applicants who are women or who are minority. (In the program considered within this study, 66% of participants were women.) Undergraduates who are offered a coveted slot are often already highly experienced in research, some even with published papers, have high grade point averages, enthusiastic letters of recommendation, and for upperclassmen who have taken it, high GRE and GRE Physics scores. Unquestionably, the REU programs are able to attract applications from and select the "best and the brightest" students available.

The REU involved in this study is situated at a highly prestigious research institute located near, but not on, a 4-year, research university campus. This institute hosts one of the world's largest and most technologically advanced collections of telescopes in the world. According to program evaluation data, the opportunity to have telescope time at this observatory is the primary reason for their interest in the program.

REU participants who are competitively selected for this program arrive to begin work shortly after the Memorial Day holiday and continue until the beginning of August. This is an awkward time for them to arrive as many professional astronomers, who will be serving as students' faculty mentors, attend a professional spring meeting during this week.

Unlike in other disciplines, where REU students often jump right into a working laboratory or a field-site, many REU students in astronomy begin their summer by being handed a large stack of journal articles which are related in some way to their work for the summer. The journals are written by scholars at the top of their respective fields, while the participants are still working at the undergraduate level. This occasionally makes it difficult for the participants to decipher and make meaning of the readings. The program involved in this study is typical in this way.

Most of the REU students are assigned workspace in a single large room. The room is configured with tables around the perimeter and students facing away from the center of the room at their computer workstations. At each work space, participants are seated in front of a Sun-computer workstation, which are completely unfamiliar to many of the students when they first arrive. Nearly all students wear headphones attached to an MP3 player to limit distraction from other students. Most students can be observed to have multiple computer windows open to communicate with the outside world, including their faculty mentors. These windows typically include email, Skype, and at least one txt-messaging program, such as Yahoo! Messenger. Additionally, students will typically have their cell phone on the desk, so as to be able to immediately respond to TXT messages when they arrive.

Research projects for the summer are generally assigned to participants, although there are some occasions in which they are offered a choice of a few different projects. In general, these projects involve data reduction of a subset of data from a larger project being completed by the mentor. Using their Sun workstations, participants are typically tasked with downloading data from a digital archive, given a pre-existing computer program code to manipulate the data to align with an existing data set, and wait for calculations to be made by the computer.

During the week, students often arrive early, usually between 8:30 and 9:00am. Their faculty mentors often do not arrive until 10:00 or 10:30am. The participants' early start allows them time to take care of communicating with family and friends, who are frequently distributed across several time zones. Each day, there is an institute-wide coffee break in the morning; all faculty, graduate students, and REU students are expected to attend. A few days each week, there are colloquium lectures given by visiting professors in the early afternoon. Some REU students attend consistently, others rarely. According to evaluation data, the lectures are frequently judged by the REU students to be quite advanced.

There is rarely a consistent time that REU students meet with their mentors. If students do see their mentor outside of the coffee-break time, it rarely is more than once or twice each week. The institute is consistently locked at the end of regular business hours and students are not issued keys. They are welcome to stay inside, but if they leave, they are locked-out; most students leave the building by 5:00 pm. This REU's general work-habit does not involve consistent to work in the evenings or weekends.

This summer program concludes with a day-long mini-conference where students make presentations to their peers, mentors, and other members of the institute. About 10 days prior to the mini-conference students and their mentors start working on building a presentation describing how they allocated their time over the summer. Therefore, the last week of the REU program is devoted almost exclusively to building an illustrated and data table filled PowerPoint presentation. According to evaluation data, many students state this is the first time they fully understand the larger scientific picture in which they have been working. For other students, it is a time to focus on generating a purposeful series of results, as they have spent much of the summer “doing a little of this and a little of that.” Many of the participants in this study indicate that they have engaged in multiple REU programs, and generally report that this pattern of activity is also typical of other astronomy REU programs.

Research Relationships

Access and Gatekeepers

In this study, the researcher had ready access to archived, longitudinal data due to her involvement with work related to evaluation of this REU program. She had served as one of several evaluators who had collected evaluation, on-site and via distance means, for eight years. Her personal involvement included interviewing, surveying, and timesheet analysis over a three year period. This was a contract position that resulted in a mid-summer and end-of-summer report to the program director, which was intended to improve the quality of the institution’s REU program.

All evaluation data, collected over the eight year period, were owned and archived by the primary evaluator. Therefore, the primary evaluator of the program served as the only gatekeeper in the first stage of the study. The evaluator readily released the data to the researcher for the purposes of this study. For the second stage of the study, there were two gatekeepers: the primary evaluator and the participants themselves. The evaluator had maintained contact with the participants through an annual email survey, and was willing to send out invitations to participate in Stage 2 interviews to all REU alumni. The alumni who identified as women and who were interested in participating in the study were instructed to contact the researcher, via email. At that point, 16 women emailed the researcher within a one week period, providing their own contact information to the researcher and allowing her to send out additional information about the research study. In this informational email, the researcher described the purpose of the study, the data being sought, and a protocol for responding to the researcher if they were still interested in participating. All 16 participants responded positively.

The Researcher as Research Instrument

> Research is an egocentric activity. … Look at what a researcher is studying and you'll know more about them than they'd probably like you to know. Doyle (personal communication, March 17, 2008)

In all empirical work, but particularly in interpretive work, the researcher is inevitably part of the research study. In every case, it is the researcher who defines the problems they will address, and the questions they will attempt to answer. The researcher also selects a research methodology from the many choices available to them, and in the process, influences the potential data that will be available as evidence. In the case of interpretive or qualitative work, the researcher also enters the work as the designer of the specific protocol used, in the form of the observer or interviewer, and finally, as the meaning maker, who transforms data into evidence, and determines what can be concluded from the whole. The researcher decides what should constitute data, what data are important enough to record, and what all of the data mean. Given this, interpretive research has to acknowledge that the researcher is part of the study. What the researcher brings to the study needs to be revealed, not only as a matter of ethics, but to allow the audience to evaluate the ways in which those experiences may be enhancing or skewing the validity of the work.

In this study the researcher's background positioned her to engage as an insider, while acting as an outsider, in the sub-culture of academic astronomy and physics. The professional astronomy world is a small, but distinct sub-culture, as marked by community practices, engagements, social mores, and perhaps of greatest impact to this study, language (Bishop, Bishop, Gelbwasser, Green, and Zucherman 2003; Bucholtz 1999). This is a culture in which intelligence is highly valued, frequently resulting in communication that is intentionally obfuscatious (Eglash 2002). The astronomy and physics academic communities are particularly drawn to shorthand communication and specialized vocabulary. According to Mitton (2001) astronomy alone has 3,200 words and abbreviations that are distinct to communications in the field. Moreover, in this community language is routinely used as a gatekeeper, where outsiders who do not share the same linguistic norms are intentionally excluded from the community (Bucholtz 1999). Or as described by Urry, social discourse within the astronomy world is frequently influenced by a culture of elitism and exclusivity (2007). Operating under the notion that language is intimately related to participation in other social practices within a community, being able to speak the language of the culture of academic astronomy, to comprehend the cultural meanings associated with places, events, and persons, requires enculturation into that community as a participant (Bourdieu 1978, 1991)

In this study the life experiences of the participants' and the researcher overlap to a significant degree, allowing the parties to communicate in the same language. The researcher and all of the participants were highly motivated in the sciences, particularly in astronomy. As the data would later indicate, all had been interested in the STEM fields since childhood and had accumulated innumerable hours of science engagement prior to high school graduation. Each had found their way into a prestigious extracurricular research program, and most attended high-profile undergraduate institutions. In the case of several participants, the researcher either attended the same institution, or studied or worked in the same department as the participants. In several instances the researcher took the same undergraduate courses as the participants, in one case, with the same professor. In every case, the researcher was familiar with the participants' professors and mentors, either by reputation or by actual acquaintance, and with the research work conducted by the professors, mentors, and the participants themselves.

The cultural knowledge shared by the researcher and participants served to enhance the work in five ways: instant rapport, the use of short-hand speech, transparency, flexibility in the interview, and as a means to insure the participants' safety. Rapport was facilitated through prior interactions and other shared experiences. In the course of the previous eight years of evaluation work, the researcher had spoken to and interviewed several of the participants, at the REU location, therefore many of the participants had already experienced an interview protocol with the researcher. These experiences may have contributed to the notions that the interview would be relatively painless and that the data would be handled in a confidential manner. As another sign of shared community, a few participants had attended talks given by the researcher at astronomy's primary professional conference, or had seen her name in the conference program. In addition, prior to conducting the Stage 2 interviews, the researcher gave the participants a brief biographical sketch of herself, highlighting some of their shared experiences. This also served as a signal that researcher was part of the community, or as one participant stated, the researcher could be viewed as "one of us."

Shared language also served to allow the researcher to understand and participate in the highly specialized language of astronomy in a way that would be inaccessible to many other researchers. In the case of Stage 1 analysis, and Stage 2 interviews and analysis, an understanding of the language allowed the researcher to progress through the enormous amount of jargon in the data. A review of both data sets revealed that approximately 35 astronomy-specific acronyms, 45 specialized research terms and nearly 60 proper names for astronomers, institutions, and programs were recorded, without benefit of definition or explanation. A fluency in the dialect of astronomers allowed *ex post facto* data to be analyzed without contacting participants, and greatly enhanced the interview sessions by allowing the conversation to focus on the substance of participants' experiences, rather than on a translation of the culture's jargon.

More importantly, understanding the cultural meaning of terms allowed the researcher to discern the nature of participants' experiences and detect moments in which clarification might be important. The astronomy community is one in which boasting about accomplishments is nearly required for success (Urry, 2007). In the researcher's experience this cultural communication style manifests differently in men and women.

As Urry describes, in the case of male astronomers, this boasting can often be obvious, aggressive, and even obnoxious (2007). The female version of this boasting behavior is more subdued, consisting of softly worded name dropping and descriptions of great success tempered by self-deprecation. If the researcher does not know the cultural meaning of the references provided, they might not know that the participant has revealed an important piece of information, and in many instances, they would not know to ask. For instance, when asked to describe astronomy related experiences, a woman might say something like: “I helped out on the optics team at Keck in the mid-90’s.” An astronomy insider would know that Keck Telescope was equipped with a highly effective adaptive optics system in 1996. It was the first operational adaptive optics system on a large telescope in the world, and serves as an icon in astronomy culture. The small piece of information revealed by the participant is a cue to be impressed, and to delve deeper into the experience. A person who is not an insider would almost certainly miss the meaning contained in this small, off-hand statement. It is difficult to overstate the advantage of insider knowledge in this regard. Another example, taken from the study, further illustrates the benefit of the researcher knowing the “characters” in the astronomy world:

> Participant (P): Another thing that was pretty important to me as an undergraduate was my observational astronomy course.
>
> Researcher (R): Really, who did you have?
>
> P: Professor [X]. He was pretty good.
>
> R: Really? Wow. I had him, too. What text was he using when you had him?
>
> P: [laughs] He was using his notes that he had bound up. [laughs] OK. I didn’t say he was great as an instructor, but he was helpful in other ways.

In this case, the researcher's familiarity with the professor's reputation as a weak instructor was a mismatch with the participant's initial statement, and cause for further questioning. Without that familiarity the statement might have been taken at face value, and the subsequent rich discussion of this instructor's impact on the participant's education would have been missed.

Finally, the researcher's position, as a non-astronomer who is part of the astronomy community provided an understanding of the risks this study proposed to the participants, and to insure a pathway that would maintain their confidentiality and professional safety. As stated previously in this section, there are threats within the community, such as the threat of honest program evaluation to participants' chances of acceptance to a top graduate school. While participants' in this study are beyond the period of graduate school application, pressures remain related to interactions with others within the community. Throughout their careers, participants will continue to rely upon the goodwill of those that they have encountered in their educational experiences, as related to hiring decisions, proposal and journal reviews, tenure and promotion decisions, and the realities of interpersonal politics in a small sub-culture. By asking participants to share their insights into their own educational experiences, this study asks them to characterize and evaluate their interactions with others in the field. In doing so, they are essentially being asked to provide honest, and occasionally unflattering, commentary on actors and agencies that have great power to impact the participants' future careers. Moreover, they are being asked to give permission to make that commentary public.

Reducing the risks of participation in the study for participants was essential to data collection.

My position in the community as an education researcher reduced direct threats, while my knowledge of the sub-culture provided me with the insider knowledge to understand and neutralize distal threats to participants. While my experiences are similar to that of the participants,' my career choices took me away from academic astronomy and into science education research. While I am a denizen of the same sub-culture as these women, I occupy a separate space within that world. Professionally, we present most of our work at the same conferences, but in different sections. Due to my work in education, public outreach, and evaluation, our circles of professional collaborators, and personal friends, overlap to a surprising degree, but I do not serve as a threat to these women. I am not likely to serve on a committee that might grant or deny access to resources, nor will I review their proposals or journal articles. It would be unlikely that we would ever serve in the same department, or be nominated for the same award. I am not in a position in which negative judgments, that I might personally make, could have a negative professional impact on participants.

However, the data collected from the participants could damage them, both personally and professionally, if its publication contained any identifying information. In the very small world of research astronomy, it is highly likely that a reader of this study could easily identify a participant. The astronomy research community is surprisingly small. The qualifications of membership in this community are nebulous, making a census difficult; however, statistics from the American Astronomical Society (AAS) and the International Astronomical Union (IAU) suggest that the number of American astronomers is approximately four thousand (AAS 2009, IAU 2009). The number of American women who are trained astronomers is much smaller, hovering at a number less than one thousand. The number of women who would have received their training in the period covered by this study is even smaller, perhaps two hundred. This study looks at the experiences of 51 women, a large segment of the available population, and takes a very close look at the educational experiences of eight successful young women. The data from the study suggests that each participant's educational pathway has been unique. To those outside of the astronomy community, it might seem improbable that participants could be identified by data presented in this paper or in a conference presentation. An insider realizes that there are only so many women who could have participated in this study, they each have a highly identifiable set of experiences, and that they are most likely separated by any denizen of the sub-culture by only one or two degrees of separation.

In researching the world of professional astronomers, having the credentials to claim status as an insider, while acting as an outsider, is uncommon, and I believe, crucial for this study. Assuring the participants that the risks were thoroughly understood by the researcher and that steps would be taken to minimize their exposure was only possible due to the researcher's unique positioning. In terms of the study, understanding the threat to participants allowed the researcher to construct a consenting procedure, data analysis method, and reporting procedure to insure participant confidentiality. Each of these issues will be discussed in the following sections.

Research Considerations

Ethical Considerations

The consenting, data collection, analysis and reporting of this study were designed to work within the structure created by two ethical concerns: the delicate nature of participant confidentiality, and the rapport between the researcher and participants. The difficulty of reporting data accurately without exposing participant identity was alluded to in the previous section, and stands as the most important concern in this study. The issue of rapport is unusual in this study, in that there was the possibility of too much initial rapport. Participants had been interviewed by the researcher, the primary evaluator, and other members of the evaluation team at least two times during the previous years. In addition, the evaluation team had interacted socially with some participants, and the primary evaluator had maintained friendly email contact with all participants since their engagement in the REU. Given the long-term relationship that facilitated this study, there was some possibility that participants might forget that they were being interviewed, and subsequently reveal information without remembering that their comments were part of a research study.

Over familiarity is a particular concern in work that involves in-depth interview, such as in this study. In-depth interviews ask participants to re-construct portions of their life histories as it relates to the subject of the inquiry. In the process of consenting participants, the researcher also shared some of her own life history. According to Seidman, this kind of interview process results in a measure of intimacy between the interviewer and the participant that can lead participants to share aspects of their lives that, if misused, could leave them very vulnerable (2006). This had ramifications for informed consent of the participants.

These concerns were addressed through transparency in obtaining consent, at the beginning and throughout the interview process, and by encouraging the participants to consider themselves collaborators in the study. Full disclosure in consenting can be problematic (Seidman, 2006) as it is possible for respondents to skew results by supplying what they believe to be the expected answer. Easing participants into the role of full collaborator can run the same risks, in addition to the risk of "overrapport" (Miller, 1952). However, according to McCracken (1988) there are potential advantages to partnering with the interview respondent. From the respondents point of view those benefits include being asked to state a case that has not been heard, engaging in the intellectually challenging process of self-scrutiny, and being offered the opportunity to experience something akin to catharsis as they make sense of their own life experiences. The primary benefit to the researcher of working with an informed respondent is the potential for more meaningful interaction with the participant. Given the highly intelligent, inquisitive nature of the participants in this study, the benefits of this approach appeared to outweigh the potential risks.

As an additional means of insuring that personal boundaries were maintained and confidentiality insured, the researcher engaged the participants in member checking the results of the study. Member checking is the process of sharing the written report with the participants of the study (Lincoln & Guba 1985), and is usually done to determine if the information contained in the report is accurate. In this case, interview participants were also asked to identify any passages that they believed might provide identifying information or make them vulnerable. As described in the following sections on consenting and data analysis, participants were assured that the data would be presented in such a way that they would have a difficult time recognizing themselves in the report. All parties who reviewed the report were satisfied with the manner in which data were reported.

Informed Consent

Informed consent is required in order to protect the participants in any study involving human subjects. In this study consent requirement was satisfied by having participants respond to an email solicitation. The rationale was that by sending out an email explaining the nature of the study and potential risks, that any respondent would be giving consent if they deliberately sent an email volunteering for the study. However, given the ethical concerns described in the previous section, this consenting process seemed necessary, but insufficient. It is the ethical responsibility of the researcher to protect vulnerable participants beyond the minimum requirement, even when participants do not believe that they need protection (Kelman, 1977). Additional steps were taken.

The decision was make to solicit participants in the Stage 2 interview through the primary evaluator of the REU. Every year since their engagement in the evaluated REU, each participant had received a follow-up email survey which asked them about their current situation and their thoughts on their REU experience. At the end of the eighth year the evaluator attached a request for interview participation to the follow-up survey.

(This email solicitation is included in Appendix A.) Participants were provided with a brief description of the study, and were asked to contact the researcher if they would be interested in participating. This fulfilled the informed consent requirement. 23 of the original 51 participants responded within one week.

As an additional means of providing for informed consent, each participant who volunteered for the study was emailed with additional information as to the identity of the researcher, the purpose of the study, and a request for contact information and a good time to conduct the research in the following two weeks. (This email solicitation is included in Appendix B.) A deliberate attempt was made to associate the interview with the REU, and with educational experiences beyond the REU. This approach allowed the solicitation to honestly communicate the purpose of the study without being leading. Beyond ethical issues, this approach also resolved a practical concern: in previous email surveys it had become apparent that some women were disenchanted with their REU experiences, and while they would respond to other survey questions, they had stopped answering questions related to the REU. By indicating that topics other than the REU would be discussed, the solicitation might succeed in recruiting those women. Twelve participants responded to this second stage of the solicitation, with a meeting time and either phone or web-conferencing information, within a two week period. Six additional participants responded after the two week period.

At the time of each interview, the informed consent process was repeated. The protocol lasted between five and ten minutes, depending on the number of questions participants asked. During that time, the researcher reintroduced herself and again described the purpose of the study. The REU was mentioned, both as the means by which the researcher and participant were connected, and as an example of the kinds of educational experiences that might be discussed in the interview. However, the REU was not made the central focus of the consenting process in order to avoid leading the participant as she told her story.

During the consenting process all participants asked questions. The questions probed for additional background related to the researcher, the whereabouts of other members of the evaluation team, the intent of the study, and proposed means of reporting the data. The following excerpts illustrate typical participant concerns.

> P: Are you doing one of those studies where you try to figure out how to get more women in astronomy.
>
> Researcher: Well, I've done that kind of work before, but that's not what I'm doing here. Right now I'm interested in what kind of educational experiences have been meaningful to you.
>
> P: Oh, OK. Cuz' I'm kind of tired of that kind of thing. If women don't want to do astronomy, it's probably not the right thing for them.

> P: What will you do with this information when you get it?
>
> R: Well, it most certainly will be published, but you're not going to see it in ApJ (The Astrophysical Journal)! [laughing] The kinds of places that I publish are not the kinds of things that astronomers usually read. The only journal I publish in that they might read would be the Astronomy Education Review.
>
> P: Oh sure, I've read that. But you're right, not many astronomers do.

P: So, can I see what you've written when you're done?

R: Absolutely. In fact, at the end of the interview I was going to ask you if I could send the data to you so that you could look it over for me. I'd like to make sure that you think I've been accurate in what I've said, and to make sure that you don't think it's got identifying information in it.

P: Oh, that'll be fun. But I would really just like to read what you find out. I don't think I need to check your work for you.

P: Will you use our names, or how will you do this?

R: No, no, not at all. My plan is to report out the data by themes, rather than by each person's story. I'm not even going to use pseudonyms; otherwise I'd ask you what you'd like to be called.

P: [laugh] I want to be "Towanda."

R: [laugh] No, no code names. The way I'm going to do it, your data will be mixed in with everyone else's, and readers won't be able to track who is who. My goal is that when I'm done with it, you won't be able to identify yourself.

P: OK, that's cool.

The benefit of this kind of interaction in the consenting process is that participants' had their concerns addressed, and immediately engaged as insiders in the research. The disadvantage to participants' assertive engagement in the consenting process was that the protocol was usually delivered out of order, necessitating a checklist. A checklist was created after the first interview to make sure that all important points were covered. The checklist consisted of the following items:

- Researcher introduction (REU evaluator, graduate student)
- Purpose (What educational experiences, including the REU have been important to women in astronomy)
- Reporting (published study, conference presentation)
- Risks (career risk, confidentiality essential)
- Right to participate is voluntary
- Right to withdraw at any time, or withdraw portions of data

In the consenting process the last two points on the checklist were particularly important. All participants were assured that the researcher understood the ease with which they could be identified and the possible ramifications. Participants were told that the data would be reported without identifying information, and that the intention was to report the data in such a way that when they read the final report they would "hardly be able to recognize [themselves]." Additionally, they were assured that none of the individuals mentioned in the interview, their hometowns, or the university's they attended would be identified. Programs they mentioned in the interview would only be identified if it could be done in such a way as to not identify any other actors. They were additionally told that they not only had the right to withdraw from the process at any time, they could also withdraw portions of their data from the report. This information was given before the interview, occasionally during the interview, and again at the end of the interview.

During the interview participants would occasionally relate their experiences that involved named individuals in the community. At no point did a participant indicate that they were uncomfortable with mentioning names. However, in the event that they changed their mind at a later time, or if they had shared information that, upon reflection, they felt to be too personal, they were assured of their right to withdraw all or some of their data from the study:

> If at any time you think to yourself: "Whoa, I don't really want other people to know that little piece of information!" just tell me. Or if you think of it tomorrow, drop me an email or call, and say "Hey, you know that thing I said about that one person. Yeah I'd feel more comfortable if you didn't report that part." And it'll be totally good with me. I won't take it personally, and it won't hurt the study.

Finally, as stated in the previous section, interview participants were asked to engage in member checking the final report to insure that they consented to content contained in the published materials.

Methodology

This study was conducted using the traditional grounded theory framework: data collection intertwined with analysis serving the purpose of theory construction, followed by additional data collection and analysis serving the purpose of refuting and refining the initial theory. The first stage of data collection, analysis and theoretical conceptualization with is referred to as Stage 1. The second stage of data collection, analysis and theoretical refinement is referred to as Stage 2.

Stage 1: Analysis of Longitudinal Data

Data sources and data handling

In Stage 1 of this study, eight years of evaluation data, related to 51 women who participated in the REU, was analyzed to form an initial theoretical conception related to the educational function of the REU, and the way in which the REU situates within the broader educational landscape. These data were collected over eight years by a primary evaluator and a team of three other evaluators, including the researcher. Data were collected from the participants themselves, the program director of the program, the REU mentor, and faculty mentors from each participant's home institution. During the course of evaluating the REU over the eight year period, some data types were collected yearly while others were collected during selected years, depending upon the evaluators' needs. Data sources analyzed in Stage 1 are listed in Table 1.

Table 1

Data sources analyzed in Stage 1

Data Source	Data Source Description	Sample Size
Participant Interviews (pre-, mid-, and end of summer)	Semi-structured interviews, archived as field notes with selected quotes	n = 144
Mentor Faculty Interviews	Semi-structured interviews, archived as field notes with selected quotes	n = 72
Participant Surveys	Various Likert-type surveys. Example included in Appendix C	n = 216
Home Institute Faculty Surveys	Semi-structured interviews, archived as field notes with selected quotes	n = 21
Participant Time Logs	EXCEL Spreadsheets. Blank copy included in Appendix D	n = 18
Alumni Follow-up Surveys (conducted yearly)	Emailed open-ended, four question survey. Example included in Appendix E	n = 197

Data cleaning

Data for all participants were coded by the year in which they participated in the REU, and the order in which they were interviewed at the beginning of their REU summer. For instance, the first woman interviewed in 2002 became "02F1." Participant identities and codes were stored separately from all data, and were only retained to facilitate theoretically sampling in Stage 2 of the study. Identity codes followed each piece of data through each step in coding, categorization and theoretical conceptualization.

In interpretive and particularly grounded theory, it is common practice to begin analysis by scanning the data sources for obvious connections between the research questions and the data. In this case, a cursory scan indicated that some of the data sources would only provide superficial insight as to the educational nature of REUs. Participant surveys and time logs largely reflected time-on-task, without any indication of active participant engagement or learning outcomes, while the surveys from home institute faculty provided unsubstantial reflections on the REU. These data sources were eliminated from further analysis. Mentor faculty interviews were largely evaluations of each participants potential in astronomy and descriptions of the tasks each participant had been assigned in their REU. This information was both from the point of view from parties other than the participants, and most often, did not lend any insight into the development of the participants over the course of the summer. A few mentor faculty interviews addressed the growth of the participants and were retained as a means of gaining insight into particular participants. All other mentor faculty interviews were eliminated from analysis. The remaining data sources, participant interviews and annual alumni , were analyzed using the process of coding typically used in grounded theory.

Coding and memoing in grounded theory

The basis of analysis of the grounded theory approach is to read and re-read the textual database (in this case interview notes and quotes, and yearly surveys) and discovers, or label, variables. These variables are called categories, concepts or properties, and their interrelationships. The ability to perceive variables and relationships is termed "theoretical sensitivity" (Glaser 1978) and is affected by a number of things, including the researcher's reading of the literature, prior knowledge, life experiences, and the use of techniques designed to enhance sensitivity.

Two of the most important techniques available in grounded theory are coding and memoing. The first technique, coding, is a means by which data are organized into categories according to their properties. In the process of open coding, items are identified from the data and are defined or arranged according to their various properties. The magnitude or dimension of the property may be described. As open coding proceeds, the data are fractured and compared for similarities and differences. Events and ideas that seem to be related to each other are grouped as categories. During open coding, data are scrutinized through constant comparative analysis (Strauss & Corbin 1990). This process frequently results in re-categorization, wherein some categories are broken into sub-categories, data are moved from one category to another, or data from multiple existing categories are moved into a new group. The result is a set of concepts that "depict the problems, issues and matters that are important to those being studied" (Strauss & Corbin, 1990). Axial coding is the process of reintegrating the categories in such a way as to begin to explain the phenomena. Axial coding looks at how categories relate to each other, and how certain properties may cross-cut categories.

These forms of coding do not occur sequentially, rather, the processes are highly interwoven, while at the same time, theory is evolving. In order to manage the large cognitive load required in grounded theory, researchers rely upon memoing. Memoing is simply the act of making notes to keep track of ideas that occur. This can occur in the margins of a sheet of notes, on note cards, or in a computer program. The method is not important. In a similar way, coding can occur in the margins, on small snippets of paper that have been cut out of larger pieces of text and color coded, or by using software. Dale Baker described her analysis for her seminal work “Letting Girls Speak out about Science” as consisting of a multitude of scraps of colored paper being shuffled around on her living room floor until they made sense (personal communication, March 31, 2008). In this case, theory generation was confined to a spiral notebook in which the coding was copied over and over again as it evolved. Memoing occurred in the same notebook.

Coding Stage 1

As the field notes and quotes from eight years of interviews and surveys were read and re-read, data evolved from three initial categories into four different findings. The initial three categories were relationships within the REU, enculturation, “astronomy” and a miscellaneous category that included interesting data that did not clearly rest in one category. By the end of Stage 1, these had become “astronomy: coding but not astronomy,” “learning how to do science,” “learning about graduate school," and "learning about the self." Examples of the types of data that fell into each initial category can be found in Table 2.

Table 2

Examples of Data in Initial Categories

Initial Category	Examples of Data
Relationships within the REU	• Saw mentor 4hr/wk (01F1) • Mentor quite busy/impatient (02F2) • The mentor "stayed out of [her]way" (02F5) • "If I have a question I ask the graduate student rather than the mentor so that I don't look too stupid." (03F6) • Research project---poorly conceived. (02F3)
Enculturation	• Info on grad school (01F1) • "Lots of long work days, figuring stuff out on your own and learning how to ask questions" (01F4) • Picking a grad school = "look for happy graduate students and warm professors" (02F3) • "You don't show up because you're on the clock, you just show up." (04F3)
"Astronomy"	• Read many articles about CCD's and photometry (03F6) • Learned IDL & UNIX (04F3) • Wanted more guidance in the science (02F4) • Wanted more astronomy instruction (02F5)
Miscellaneous	• [the observatory] was boring (01F2) • Many visiting astronomers discouraged her from going into astronomy (work is hard, not interesting, tough to get a job) (05F1) • Attended colloquia (01F1)

Over the course of reading the data several times, the categories began to take on conceptual meaning as data shifted. This shifting comes with familiarity with the data, and through the attempt to create coherence. It is a non-linear process that results from properties in the data that become increasingly relevant with time. Examples of the data that supported the resulting categories are given in Table 3.

Table 3

Examples of Data in Resulting Categories

Category	Examples of Data
Astronomy as coding	• She was "using [her] computer skills, not [her] astronomy knowledge" (05F5) • Saw is as mostly programming and analysis (05F2) • "Astronomy is a lot of coding" (01F2) • "debugging code is frustrating" (05F3) • "tedious" (01F4)
Learning How to Do Science	• "this was doing other people's dirty work" (02F2) • "the research was poorly conceived" (02F3) • Given data to "play with" as a means of learning the domain (04F1) • Mentor encouraged her to "be independent and think about her results" (04F1)
Learning about Graduate School	• "Picking a mentor is much more important than which program you attend" (06F2) • "it's important that there are multiple people you can work with in case it doesn't work out" (06F1) • Learned a little about how to get into grad school (01F3)
Learning about the Self	• Learned to strike a balance between work and life • Learned that she needs a quiet work environment

As the data began to form these categories, there was concern that individuals who had experiences particularly poor experiences might skew particular categories. Data indicated that two individuals had REU experiences in which their research projects were unfortunately aborted. Their data were not considered in the categories related to learning science and astronomy. Another participant experienced a family tragedy during her REU, making it difficult to determine which of her responses were related to the REU and which were related to external forces. Due to the unusual nature of her experience, her data were not included in the analysis .

The initial category of “relationships within the REU” does not appear in the final list of categories as it resolved into a cross-cutting category through axial coding. Rather than being viewed as its own category, the ways in which participants related to their mentor, graduate students, and their overall REU experience came to be seen as a property that might, or might not, influence any of the four previously listed categories.

Selective Coding

In the final step in the Stage 1 analysis, the data were selectively coded, or integrated, to develop a description of “what is going on here” (Strauss & Corbin 1990). This theoretical conception is rarely represented by one lone case, or by the words of a single participant. In this study, each category’s description, and the description of the cross-cutting category, represents the point of view of many women. Findings of this nature are not represented as raw data, but as narrative descriptions. This part of the analytical process produced the results which can be found in Chapter 4.

Stage 2: Theoretical Sampling

Rationale

Stage 2 of the research study involved interviewing a theoretical sample of participants in order to examine and elaborate the theoretical conception developed in Stage 1. Theoretical sampling is an idea first described by Glaser and Strauss (1967) and is a central technique in the iterative process of grounded theory. Theoretical sampling is different from probabilistic, random or convenience sampling in that the researcher is not attempting to capture a representative population, or to learn from the sample they have immediately available. Instead, the researcher is attempting to collect data from a sample that is likely to lead them to a deeper understanding of the previously analyzed data, and which will assist them in developing a framework for understanding the phenomena (Marshall 1996).

During Stage 1 analysis, four findings related to educational benefits of REUs, emerged from the data. These findings varied in dimension, with no finding appearing to have important impacts on the participants. The purpose of the Stage 2 interviews was to engage in conversation with participants who were most likely to refute the weak impacts indicated in Stage 1. In other words, the participants selected for the interview were those who were most likely to have experienced learning gains in the REU. The importance of deliberately searching for disconfirming evidence in the form of discrepant cases in order to avoid premature conclusions is a recurring idea in the literature (Erickson 1986, Lindesmith 1974, Mehan 1979)

Additionally, while analyzing the data in Stage 1, it appeared as if the evaluation protocols may have influenced the data, by the same process seen in the studies described in Chapter 2. That is, by asking a participant what they learned about a topic, we are asserting that something was, in fact, learned. This encourages the participant to respond with some learning gain, of whatever magnitude. In the same way, the evaluators asked participants if they had learned anything about graduate school. In response, several participants described rather vague learning outcomes related to graduate school. The Stage 2 interview protocol deliberately avoided asking participants about the REU's impact on their knowledge of the graduate school culture in order to see if related data would be volunteered.

Finally, the evaluation data analyzed in Stage 1, did little to address the first set of the study's research questions:

- In what ways does the REU serve to interact with the continuum of participants' other life and educational experiences?
- Is the REU serving to provide educational experiences that reinforce previous learning or does it make a unique contribution?
- How does the REU experience situate within the larger context of participants' experiences?
- What is the magnitude of educational power of the REU experience, as situated within the larger field of participants' other educational experiences?

The interview protocol in Stage 2 was designed to add "density" in this area (Strauss & Corbin, 1990). Reviewing memos and raw data in an attempt to find additional data related to this question, had not been fruitful. Stage 2 represented a decision to return to data collection to "fill in" this category.

Participant Selection

The participants chosen for the interviews were those who were successful in the field and who demonstrated the ability to be reflective and articulate through the evaluation data. As the REU is designed to educate and retain women in the field, the interview participants were all successful in astronomy, even if in a closely allied field, such as instrumentation. All participants had retained into and through graduate studies, and were placed in high profile institutions. In the case of two participants, women were chosen due to the REU mentor's assertion that he had witnessed scientific maturation of the participant during the REU. Finally, all of the women interviewed in Stage 2 had demonstrated the tendency to be both talkative and forthcoming in previous encounters, increasing the chances that they would be open in the interview process.

Participants were chosen from the eighteen women who responded twice to the solicitation. (For details of the solicitation process, see *Informed Consent* in the previous section.) Participants were ranked using the criteria described in the previous paragraph, and interviews were conducted until the data reached theoretical saturation. At that point, analysis of interview data failed to produce additional properties of dimensions within the categories, indicating that the analysis accounted for the spectrum of variability within the context of the study. In total, eight women were interviewed.

Interview Protocol

The interview protocols in Stage 2 were semi-structured and audiotaped. Field notes were taken during the interview, but following Glaser (1998), were not transcribed.

The interview protocol in Stage 2 was direct, and intended to build upon the obvious intelligence of the participants. Given that the participants are researchers in a highly technical, positivist, quantitative field, the nature of interpretive research was briefly explained. Then, research questions were explained, in fairly vague terms, to let the participants now what kind of information that was of interest. The remaining protocol consisted of three questions:

1. Along your road to getting where you are now, you've had a great number of experiences that have turned you into an [astronomer/engineer/scientist/etc], or that have taught you how to be an [astronomer/engineer/scientist/etc.]. Can you tell me about those experiences? People you've known, classes you've taken, research that you've taken part in…. They can be a big or as little, as formal or as personal as you like.
2. How was [that experience] important for you/ what did you learn there/how are you different now than you were before?
3. How would you rank these experiences?

The third question had its own protocol which will be described in Chapter 4.

The interviews with these eight women were casual, free-flowing, and entertaining. Each interview last approximately an hour. During the interview process, attention was given to interviewing technique. Specifically, the interviewer talked far less than the respondents. In listening, the interviewer attended to the "inner voice" (Seidman 2006). The inner voice is the voice that a speaker uses when they are not aware of their audience, when they are unguarded. When a more public voice was sensed, typically at the beginning of the interview, the interviewer used a variety of exploratory questions to elicit more revealing details. A conscious effort was made to avoid asking leading questions or to transfer the interviewer's experiences to the participant.

At the end of the interview participants were reminded to call or email the researcher if they had concerns, or if they thought of additional information that they would like to share. Three of the eight participants sent emails adding detail to the information that they shared during the interview.

Coding Stage 2

Repeated reviews of the interview revealed data that neatly aligned with the existing categories. Data were coded in the same manner described previously. (See *Coding Stage 1*.) Examples of the data that influenced the analysis in each category are illustrated in Table 4.

Table 4

Examples of Stage 2 data associated with conceptual categories

Category	Examples of Data
Astronomy work is coding, not astronomy	• "I didn't know how much computer programming it would be. I hadn't done that before." • "I took [a sophomore course] which was heavy on coding." • "I learned programming at [a summer program] and I had a undergrad experience after freshman year where that's all we did."
Learning How to Do Science	• "My other projects were longer and there was time for projects to evolve." • "In the REU I was working someone else's questions, which wouldn't be bad if they were good questions." • "Against the backdrop of my undergraduate experience, the two REUs were a real let down. I had two different advisors that handed me old data sets that were lying around. There was no engaging in questions, or working on the conclusions."
Learning about Graduate School	• "Everyone who got into my grad school had an REU. I think it helps with admissions." • She had already won many awards and had been in prestigious programs, since 7th grade. "I know the system." • She worked with post-docs and professors at her home institution. They had told her about grad school. • "Everyone at [my undergraduate institution] goes to grad school. Liberal arts colleges are like that."
Learning about the Self	• "I already knew, since I was 11 years old, that I wanted to do this." • "I developed a resonance with the astronomy community when I was in the Young Scholars Program (in 8th grade). I belong in this community." • "I was an undergraduate in the best astronomy program in the world. If I hadn't done the REU I'd still be an astronomer." • "I have always wanted to know how the universe works. Always."

Reporting the Findings

In the final step in the Stage 2 analysis, the data were selectively coded, or integrated, to develop a description of "what is going on here" (Strauss & Corbin 1990). As stated in the description of selective coding in Stage 1, the results of that coding, the findings in grounded theory are not reported as raw data. Since data collection, analysis, and the creation of theoretical conceptions are interwoven, iterative and simultaneous, reporting results as frequency counts, or quotes without interpretation, would be fruitless. Instead, the theory is presented as a narrative in which meaning is created out of the grounded theory process. The findings of this study are reported in Chapter 4. Theoretical implications, and their relationship to existing literature are discussed in Chapter 5.

CHAPTER 4: RESULTS

In pursuing a description of the nature of undergraduate research experiences as being transformative educational experiences, longitudinal data from evaluation reports and participant interviews were analyzed. This chapter describes the results of that analysis by pairing the categories found in the *ex post facto* longitudinal analysis with related data from the follow-up interviews. Each finding is then followed by a set of brief remarks that interpret these data in light of the constructs of continuity, interaction and transformation.

As described in Chapter 3, the professional astronomy community is a small one. In order to protect the privacy of the women who participated in this study, the results are described in terms that minimize the likelihood that an individual person might be identified. One approach to handling these data would be to describe an unnamed individual in what might seem to the outsider to be broad terms:

> *Participant A engaged in [a particular NSF summer program], where she was mentored by [a particular researcher]. There she worked on [a specific research topic]. She later attended an REU program at [a specific institution] where she worked on [a second specific research topic].*

A description such as this one would certainly be informative for members of the astronomy community, as their insider perspective would allow them to translate this information to discern the nature and quality of the participant's research experience. However, that insider knowledge would also allow them to easily identify the subject. In this small community, a biographical sketch describing the series of research and other academic activities experienced by an individual woman would be highly unique, and would provide for easy identification.

Therefore, results are described thematically, the names of mentoring researchers are not included, and descriptions of the research work are general rather than specific. Direct quotes have been edited to remove identifying information. Analysis was conducted to explore relationships across findings for individuals, but this analysis is not described except in instances that were particularly interesting or that led to specific insights. While this approach does not provide the level of richness or insight that might be possible through a more biographical approach, it represents a compromise that values the trust these women extended in sharing their experiences.

Four Findings in the Educational Experience of Women in an Astronomy REU

Finding 1: While some participants indicated that they came to understand astronomy as a computer-dominated endeavor, participants did not describe content-knowledge gains in astronomy.

"…you don't need to know any astronomy to do astronomy."

Stage 1 Results

Before coming into the REU experience, a number of participants held a preconceived notion that the work of an astronomer is largely dependent upon a large knowledge base in astronomy. This knowledge base can be loosely defined as a general knowledge of astronomy related content and concepts, in addition to the mastery of physical laws and mathematical abilities that would be required in the field of physics. In several cases across the study participants stated that it was their love for the astronomy content that had inspired them to choose an astronomy major over majors in physics, engineering, or mathematics. Participants in later years of the study were asked about their own early experiences in science. Those who mentioned experiences related to astronomy spoke passionately of looking through telescopes or watching Space Shuttle launches with family members. Many spoke romantically of long-time emotional connections to the aesthetic beauty of celestial objects, with some participants extending their appreciation to the mathematical elegance of the universe.

- I collected Messier objects with my uncle when I was in about elementary school. Lots of cold nights out in the field, blankets, hot chocolate.... There's a thrill to planning and chasing these things. So beautiful. Even now. I can look up a crystal clear picture of M51 on the internet, but you know, it's not the same. I want it to be mine.
- I've always wanted to know how it works. The more I think about the way the Universe works, the more amazed I become. It's like the equations that describe the high school physics of it all. What are the odds that the formulas for gravitational attraction, and the attraction between charges, are so similar? When I think about everything I've learned, I can't help but believe that there's a God. Beauty like that can't be random.

Overwhelmingly, participants had entered the astronomy believing that work in academic astronomy would provide them with a means to professionally engage in a field that they would intellectually and emotionally stimulating and in which they have developed a considerable knowledge base. This conception is meaningful to participants in the cognitive and affective realms and may situate significantly in terms of identity for these women. However, during and after the REU, a majority of participants experienced a conflict between their previous conceptions of the work of astronomy and the reality of the work as observed through the REU.

> I love my stars. I love them! I want to collect them and put their spectra in a scrapbook like I'm collecting butterflies. They're my little butterflies and I could do what I'm doing right now for the rest of my life. Unfortunately, it's not likely that anyone is going to pay me for this. I'm going to have to go to graduate school and study someone else's butterflies. I'm going to have to code...if I'm going to be able to get a job.

Of the findings from this study, this finding has the greatest dimensions. Ten out of the 51 participants reported learning that the work of astronomy is largely related to computer programming. From the participants in the first year of the study to those in the last, there appears to be a recurring theme:

- It seems like you don't need to know any astronomy to do astronomy. I don't use anything I know about astronomy to do this stuff. It's a lot of plugging in numbers and waiting [for the computer to finish]. I'm using my computer skills, not my astronomy knowledge.
- Astronomy is really about [computer] programming and analysis, and that's not what I thought it was going to be.

Frequently, participants reported that programming skills were the most important skill in their research experience, as evidenced by the amount of time allocated to programming tasks. Participants reported learning how to use computer platforms, databases, and software such as UNIX, VIZIER, MOOG, and IDL, which are necessary skills for the professional astronomer. However, only rarely did participants describe these learnings in terms that ascribed value to the skill; one participant did explain that she was glad to have improved her programming skills as she will need them in the future. But, more commonly, the majority of participants displayed frustration:

- My work is just getting numbers from papers and adding a few of my own and then I press "integrate" and then it's waiting and waiting and waiting…. Debugging code is frustrating.
- For the first four weeks all I felt like I did was getting data from VIZIER, and since then, plugging it into MOOG (an analysis program).

When directly asked what she had learned over the summer, one participant replied:

> I learned a lot about what the life and tasks are like for a professional astronomer. It's knowing how to program and some of knowing how to interpret data.

Another potential educational task given to them by their mentors was reading refereed articles from journals and attendance at colloquia. However, these tasks were frequently seen by the participants as irrelevant to them as educational experiences. The journal articles were often related to the research project that they were doing, but were often highly specialized. Participants described them as difficult to read, at best, and completely impenetrable at worst.

- The journal readings sucked.
- When I arrived, I was handed a stack of journal articles to read for the first two weeks while my mentor was out of the country.
- I made a list of questions to ask [my mentor] about things that I didn't understand, but I had about 12 pages! Too many to ask, so I just kind of pretended that I understood. In the end it didn't matter, as the work that I did didn't have anything to do with [the journal readings]. I have no idea why [my mentor]had me read them.
- I enjoyed going to the weekly colloquia. Because it got me out from behind my computer. And there was free coffee. But I really didn't understand any of it.

Assigned and read in a rather decontextualized manner, participants found these experiences nearly impossible to integrate into their previous knowledge or to apply to their summer REU research project.

An additional experience that is intended by the mentors and expected by the participants to be the highlight of their REU is the trip to observe at the nearby observatory. While many reported that the trip was enjoyable, many others expressed disappointment. They most often functioned as disconnected observers to the work rather than participants. Many noted that the work of the astronomers is most often done at a remote computer terminal rather than at the telescope itself. The work that many conceived of as "astronomical observing" was most often conducted by one of the telescope operators, rather than the astronomers. For many, the romantic notion of "observing on the mountain" and the reality did not match.

- I went [observing] for two nights. I didn't go with my mentor as he wasn't observing this summer, so he arranged for me to go observing with someone else. It was cool to be up there, but it got a little boring just watching.

- The only thing that they let me do was at one point they let me use the computer to rotate the dome. It was cool. It didn't last very long, but not everyone got to do that.
- On my observation run? I learned that astronomers don't actually do anything. If you want to be up there really interacting with the observatory, you have to be an operator or an instrumentation specialist.

The idea of being in the dome when the doors are opened, and watching the telescope slew to the portion of the universe that you have chosen to explore, the stars glittering on a velvety sky as viewed through the dome shutter, is likely enough inspiration to fuel aspirations to astronomy research. Beige cubicles in an off-site lab, with desks covered by computer monitors and empty take-out boxes, did not resonate with these women in the same way, leaving one to say: "[the observatory]…it was boring."

While most participants did not expect their REU to consist of computer programming exclusively, many did expect to add to their astronomy knowledge base. However, of the 51 women involved in the study, only two reported learning any additional astronomy content knowledge, with one participant learning "some [infrared] astronomy" and another reporting that she learned about "the nature of magnetism in stars." An additional participant reported that she "read many articles about CCDs and photometry," indicating that she now knows more about the tools of collecting particular types of astronomical data than she did before the REU. In contrast, several participants stated that they wanted more instruction in astronomy and more guidance in the science of astronomy than they received. This was a case of frustrated expectations for many.

- I didn't use any of my astronomy knowledge to do this research project.

- I read all of those articles, and went to the colloquia, but I don't know anymore astronomy than I did when I got here. And my mentor didn't tell me anything new about [the topic we were studying]. It's sad, really.
- You should also know that I didn't learn anything this summer.

Stage 2 Results

Inductive analysis of the longitudinal data in Stage 1, provided evidence supporting the assertion that REU experiences serve to educate some participants about the nature of the work of astronomy. Specifically, the data suggest that the REU experience teaches participants that the work of astronomy is dominated by computer programming and analysis. Interview data failed to strongly disconfirm this hypothesis. Of the eight women interviewed, three reported that the REU served this educational function. Each of these three women stated that they were previously unaware of the significant amount of astronomy research time allocated to coding and debugging at a computer terminal, prior to their experience during the REU. The five remaining interviewees indicated that they were already fully aware of this prior to the REU. Four of these five women stated that their home institutions required coursework which focused on computer programming and analysis. The remaining participant stated that she became aware of the computer-based nature of astronomical research through participation in the Summer Science Program, an enrichment program in which gifted high school students complete research projects using college-level astronomy, math, and computer programming. In the end, it is observed that a little less than half of the interviewees stated that they learned more about the computer-oriented nature of astronomy through the REU than they already knew. These data agrees with the findings of the previous hypothesis and serves to verify the magnitude of the category. It appears that the REU serves as an educational experience, in this way, for some small portion of the women; between one-fifth and one-half of the participants in the two data sets report that the REU increased their understanding of professional astronomy as a largely computer-based endeavor.

Remarks

The extent to which participants found the experience to be educational, was a result of the interaction between the current experience and those that came before. For some participants, particularly those who had attended 4-year liberal arts institutions, their prior conception of astronomy work was largely influenced by their coursework for their degrees, in which proficiency in astronomy was equivalent to strong content knowledge in the field, rather than computational skills. For those participants, the REU interacted with their continuous prior and subsequent education in such a way as to create conflict, leading to a conceptual shift, from astronomy as an aesthetically pleasing and emotionally satisfying endeavor, to one dominated by programming. This shift resulted in a mixed transformation, where the positive benefits of participants becoming better equipped in the field was countered by the negative effective of reducing some participants' emotional connection to astronomy. For those participants who had prior experiences that taught them about the computational nature of astronomy, the REU was merely part of the continuum of experience, resulting in little important interaction. These participants were not transformed by their experience.

The extent to which participants were educated with regard to their astronomical content knowledge was also influenced by continuity and interaction. In cases where the astronomy content of the REU project was delivered through decontextualized journal articles and poorly understood research projects, the content knowledge was so discontinuous with prior experience that any interaction between the present experience and those that come before could not occur. Where there is no interaction, transformation cannot occur. In other cases, the content of journal articles and research projects was well connected to prior experience, to the extent that it interacted smoothly within the individual's educational continuum. In these cases, learning may have been reinforced, but in no case did an individual report that their astronomy content knowledge was greatly increased or transformed.

Finding 2: Participants did not describe an increased understanding of the scientific process as a result of the REU.

"…it's doing someone else's dirty work…."

Stage 1 Results

Just as many participants anticipated learning considerably more astronomy subject matter knowledge during their REU, many also expected to gain substantial insight into astronomy research practices and methodologies. Although a few participants reported an experience that could be likened to the activity of practicing scientists, the majority reported that the activities of REU participants, and frequently the activities of graduate students they observed, are more reflective of the work of technicians rather than scientists.

There are an extraordinary number of ways in which experts define “scientific research” Various panels of experts have addressed this issue, with each panel describing “scientific research” in terms that differ in subtle way (American Association for the Advancement of Science 1989, National Research Council 1996). However, for the purposes this study, it is reasonable to state that we can reduce the complex task of conducting scientific research to acts such as asking a research question, devising a means of addressing that question, collecting data via that means, analyzing that data, and drawing conclusions based upon that data. Participants in the REUs report that their work assignments are usually constrained to the realm of analyzing data. A few students (three out of 51) reported that they also collected data, but none of these students collected data that they were using in their own projects.

In much the same way, while most participants presented their work at an end-of-summer symposium, the content of these presentations largely consisted of long narratives of the analysis processes used. Analysis of field notes indicated that the presentations of results were few, and conclusions are quite rare. In the project evaluator’s field notes, these talks were likened to be more similar to “what I did over the summer with my time” than to what science they were conducting. Many appeared as co-authors on posters presented at the American Astronomical Society meetings, but their contribution was limited to a small part of a much larger work conducted by their mentors. There was scant evidence to suggest that they were involved in generating the conclusions or findings from the work. In an attempt to further explore this finding, a broader survey of all longitudinal data was conducted. In only one case, involving a male participant, was there an occasion where the participant collaborated in crafting a research question. All other participants engaged in a small piece of a much larger work, most often stepping into the middle of the research and leaving before the end.

Not only were participants limited to collaborating in one or two aspects of the research, they frequent indicated they did not understand much of the broader context of the work in which they were engaged, suggesting that they were being trained to function as technicians, rather than scientists, in the research process. This suggests that the REU students were learning to function as one who provides technological or technical assistance or support, rather than engaging in the creative work on a theory-laden, or theory-producing basis. Indeed, it is difficult to find evidence that participants were required to actually understand the project they were working on in order to accomplish their assigned task(s). Over the course of eight years, many participants were able to describe the project that they were working on, but only in broad, frequently vague terms. For instance, a participant might have said that they were trying to determine the metallicity of certain stars, because this information might shed light on issues related to origins. But upon questioning, it was unsubstantiated that they knew what the next steps in the reasoning chain would be, if they had been successful in tabulating or coming to know the metallicities.

> R: How does you project fit into the larger picture of astronomy.
> P: My mentor says that completing this work will add to our understanding of how stars evolve.
> R: What does that mean?

P: Umm...I don't know. I just know that that's what he told me.

Many participants found that their project continued to be "sort of a black box" at the end of their study. Their mentors occasionally tried to address this lack of theoretical understanding by having participants read journal articles early in the process, but as demonstrated in the previous subsection, this tactic frequently fell short of meaningful educational impact.

This lack of meaningful engagement may explain part of the frustration discussed in the previous subsection. When participants described the work they did in their project as "tedious", it is highly likely that the evaluation is derived from both the disconnect between astronomy and the tasks assigned, and from the lack of participation in the brainstorming and creativity that is part of the scientific process. The judgment, "the work was tedious," would sound the same. It seems reasonable to say that both factors contribute. Certainly, there were several participants who were quite direct in stating that they saw themselves as being intellectually disconnected from the work being conducted:

- This isn't really my project,…
- I'm just doing other people's dirty work.

Of the 51 women in this study, only two provided any exception to this pattern. In the fourth year of the study, two women worked closely with a single mentor. Both women were housed in the mentor's personal office space, rather in the larger room of cubical with the other REU participants. The project's lead evaluator's notes described their working relationship as being much more interactive than most REU/mentor relationships. In this instance the women came into a larger idea for a project, but their specific piece of the project was not predetermined prior to their arrival. According to the mentor:

> They were encouraged to play with the data as a means of learning the domain...to be independent and think about their results, develop hypotheses, and test them,

Given the mentor's description, these two women had an atypical experience, involving characteristics more common to an inquiry notion of engaging in science. The mentor also mentioned that he had noticed both women become very confident in their abilities to do scientific research. These reports were not from the women themselves, and these women did not describe their experiences as being deeply engaged in the processes of science. However, from the expert perspective of the evaluator, this pair represents a potential departure from the experiences that engaged the other participants, highlighting the difference between women in REUs working as technicians and working as scientists. This anomaly in the data served as cause to include these two participants in the interviews conducted during Stage 2 of the study.

Stage 2 Results

Through the Stage 1 analysis of the longitudinal data, evidence emerged supporting an assertion that REU experiences do not serve to educate participants about the nature of the scientific process. The data from the interviews provided no disconfirming evidence. This result was consistently observed despite a deliberate decision to interview the two women who appeared to have the most authentic science experiences during the eight years of the study. Further, interviewees knowledgably discussed other REU-like programs, in which they engaged in short-term (6-10 week) research at locations other than their home institutions. None of these short term projects were described in ways that reflected authentic research experiences.

The veracity of this assertion rests upon the credibility of the participants, and their ability to make meaning of their experiences. The interview data suggest that these women had a large body of research experiences outside of their undergraduate REU experiences, with some participants reporting and describing a decade of research experiences prior to the REU. These experiences came in the form of interacting with family members in the domain of science, engagement in science enrichment programs during their middle school and high school years, and through undergraduate academic year mentoring and research experiences. In order to highlight their perceptions of the REU experience, with regard to developing an understanding to the scientific process, the following subsection describes data demonstrating a wealth of knowledge that these women possessed about the scientific process prior to the REU.

Knowledge of the Scientific Process Prior to the REU

Four of the eight women provided data which suggest that their conceptions of the work of science were developed through interactions with family members. Some of this came through rather formal activity while much came through modeling and informal interactions. Participants reported instances in which grandparents worked with them to create collections of labeled and researched geological or entomological specimens. Others reported taking classes from their parents, through Girl Scouts or 4H programs, in which they studied topics such as geology, entomology, botany. In another instance a woman took years of sewing classes taught by her mother, which she describes as experiences in applied math, saying: “I’ve done trig[onometry] when I’ve done sewing projects.” These experiences began as early as elementary school and were on-going.

Interactional experiences involved growing up in homes rich in STEM professionals. In one instance a participant reported that all of the adults in her family were active in STEM, including a grandfather who was one of the early computer programmers, a great-aunt with a doctorate in computer programming, and a great-grandmother with a doctorate in astronomy. These family members brought their work into the home, and “constantly emphasized the practical ways of engaging in science.” Others reported having two parents who were both STEM professionals:

> My parents were both always at it. I’d say that for me they really modeled the science as an enterprise of background research and empirical work.

In another instance, a long time family friend who functioned as an “uncle,” was a dean of a school of technology and routinely toured his young “niece” through the labs in his school, where she observed, discussed and engaged in the activities of the labs.

> He took me around and showed me the labs, and let me hang out. I got to see what was going on in the research groups, and see what it’s like to do engineering work. The campus was my playground when I was growing up. So, being part of academic STEM is something I’ve always known.

These women describe substantial learning experiences throughout middle and high school which they clearly indicate as being “transformational”. In these experiences, the women engaged in extended and extensive research experiences, where they not only served to collect and analyze data; they frequently participated in the development of research questions, methodologies, and conclusions. Participants were engaging in substantial research projects as early as 10 years of age. In one instance a participant was invited to engage in a harbor study by her elementary school teacher. Together the two charted and analyzed harbor core samples over several weeks, a study the student converted into her first science fair project.

> After my sixth grade year my teacher asked me to join her on a summer research project. We were part of a larger study that a group of scientist were doing out in [the harbor]. They were looking at the change in runoff contamination in the harbor over the course of time, and our job was to help with the samples and with the analysis....It lasted about six weeks.... The next year [my teacher] helped me to turn the project into a science fair project. She really put a lot of time into me.... That was the first time that I was able to do real science.

On a different occasion a participant attended the NSF Young Scholars program at a world class observatory, which led to connections at a second premier observatory. At this second observatory she shadowed working professional astronomers during the years between 8^{th} grade and high school graduation. There the astronomers assisted her in crafting her own research questions, developing methodologies, analyzing and reporting out her results. By the time she was fifteen, she had earned the respect of the astronomers to the extent that she was given her own set of keys to one of the smaller telescopes at the observatory.

This pattern of early engagement in a high quality program, followed by extended mentorship and engagement in authentic research is common to half of the interviewees One woman described a series of experiences that began with her close interaction with a high school science teacher who helped her craft an astronomy-based science fair project.

Her success on that collaborative task led to extended interaction with a larger, local amateur astronomy club where the veterans taught her "how to observe." These connections brought her into contact with an astronomy faculty member at a local college who mentored her for two years.

> We met about once or twice a week. Sometimes at the college, but sometimes either at my house or I would go over to his house.... We spent that time with him teaching me the kinds of skills that I needed in order to be able to use [the college's] astronomy facilities. And he taught me how to really craft questions, how to work out the methodologies. He really helped me to work out how to do astronomy as a science fair project, which isn't easy.

Other participants describe summers repeatedly spent at high profile programs such as the Research Science Institute and the Summer Science Program. Still others describe immersion in high school based academies or magnet schools that focused on science, mathematics, and/or engineering. In each case, these women describe one or more mentors who taught them that "science is more than words," and that working as part of a project is valuable "but if you're not working on at least some of your own questions, you're just a lab assistant."

These participants continued to learn about the process of scientific research in undergraduate experiences, unrelated to REUs. These experiences came in the form of long duration academic year mentoring with faculty and academic year engagements that continued through the summer. With the exception of one participant, all of the women interviewed described sustained interaction with research mentors. In five of the eight interview cases, these women connected with a faculty researcher during or at the end of their freshman year, and maintained an ongoing relationship that lasted throughout their undergraduate years. One participant met her future advisor during a summer program after her junior year in high school. Their work together began that summer, continued on through several projects in her undergraduate years. While she describes working with other faculty on smaller projects, this primary relationship was a constant that continues to influence her current work.

A second participant describes approaching a faculty member for summer work during her freshman year, and the resulting activity, as the most important factor in understanding how science is done. She reports that while it was only her freshman year, it was also this faculty member's first year at their institution and the research group that was being formed was still developing. As a result, she found herself in a summer office space, surrounded by researchers of many different academic ranks. She reports:

> It was a very unsettled summer. There was a lack of pecking order that you usually see in these situations. So I could go into just about anyone's office and ask them for help. And you would see people doing that all up and down the hall. I was the lowest man on the totem pole, so I couldn't really help anyone else, but I could be there to discuss the ideas. There was a community feeling and I felt like part of that community.

Further, she describes her mentor as "a great research advisor:"

- We'd talk about the programming and interpreting the plots. She would show me how to look for biases in the data, and when it was OK to describe something as a trend. It was amazing because [she] really thinks out loud, so I could talk to her about the data, and hear what it sounds like when a more experienced person thinks about these things. My work with [her] changed how I think about science. How I look at a data set is critical, and it took a huge leap working with [her].
- We'd talk about the ideas, and we'd come up with the next steps together. She was certainly the one in charge, but it never felt like that. It was our work, and sometimes nothing came of it. Sometimes we would try to look at old data using [new methods] and what we found was exactly what everyone had found before us. So it wasn't that we were making great

> discoveries, but we were asking questions and figuring out how to answer them. It was a wonderful, wonderful experience.

As further evidence of the educational research experiences of the participants, three additional women described relationships in excess of three years with a single mentor. These mentors engaged these women in the real world of astronomy research, which is not always as pleasant as the cases described above. In one case, the participant engaged with a faculty member who she described in affectionate terms, even though she judged him to be below average as an instructor and frustrating as a research mentor. She described situations in which the mentor would ask her to complete a research task in a week, only to find that she had to return to him without the task completed. She remembered that she would return to him and ask him to "tell [her] the answer or the correct process," but he frequently would not tell her. It was only after working with him for two years that she realized he was asking her to interact with truly novel problems. She stated:

> I didn't know how to tackle his problems. I eventually realized he was asking me to do things he didn't know how to do…. I learned that even a full professor at [a prestigious research institution] doesn't know everything, and that it's OK. Research is a messy thing and sometimes you have to try several different approaches, and really problem solve before you can get anywhere…. And he helped me to get research experience at [a nearby major observatory.] Even when I did poorly in his course, he kept me on in research.

In the previous case the participant developed a collegial relationship with her mentor which greatly enhanced her experiences. However, data from other participants indicate that they learned a great deal from extended experiences with undergraduate mentors even in the absence of affection. Pointing to just how small the astronomy research community is, two interviewees described extended research experiences with the same faculty member. Although their experiences did not overlap and happened in different years, both described him as “not very nice.” They did not sense that their mentor was encouraging; in fact, they perceived just the opposite. However, in both cases the women describe learning new skills, being exposed to the vagaries of the research process, and “talking science” through their interactions with their mentor.

In another case, the interviewee was neutral with regard to her relationship with her mentor. However, in her report on the work she conducted over two summers, she indicated that she was given two broad tasks that lacked clear methodologies. Her task was to research what was known about the problem, and to devise and implement potential methods for addressing it. She collected and analyzed data, and reported her results to her supervising research scientist. The tasks she was assigned were rather sophisticated, including the potential to use untested, emerging technologies to image extremely faint objects at a time before this was successfully accomplished by larger telescopes. She was clearly engaged in authentic research and development on a novel and important topic, and she was central to the research process.

Participants’ perception of the science process in the REU

Clearly, these women had significant, sustained research experiences that transformed their knowledge of the scientific process prior to their REU. While their experiences do not position them as experts on astronomy research, it does provide them with the baseline of knowledge needed to comment about summer research experience of this kind, in an informed manner.

Only one interviewee described the REU as an experience in which she engaged in "real science." This participant attended a liberal arts college and did not have any extended research experience at her home institution. This participant stated that prior to the REU, she engaged in science laboratory courses during her high school and undergraduate years, but:

> P: That was "fake science."
>
> R: I think I know what you mean by that, but I also might not. What do you mean: "fake science?"
>
> P: It where you look like you're doing an experiment, but you're really just "going through the motions" to come up with answer that you can find in the textbook.
>
> R: How was the REU different than that?
>
> P: The REU was the first time where I was working on a problem where the answer wasn't already known.

However, the participant described her response to the experience as affective rather than cognitive. Given hindsight and the benefit of extensive research experiences in graduate school, she did not describe her REU in terms of an educational experience in learning more about the scientific process:

> Since then I've had a few other research experiences, and I know that the work that I did [in the REU] wasn't exactly the real thing either. But it was the first time I *felt* like I was doing real science, and it was exciting.

As was typical of other interviewees, this participant does not provide strong evidence that the REU transformed her knowledge of the scientific process, and therefore does not disconfirm the original hypothesis: the REU does not appear to function as an educational experience in which this type of participant develops their understanding of science as a process.

This finding is consistent with the interview data from the remaining participants. Although these participants were recruited through a particular REU, four of them had engaged in more than one program. To account for the possibility that this finding is specific to this REU program, the interview data related to other REUs was also examined.

One participant repeated the statement that she gave in the end-of-summer interview years before in which she stated that she had learned analysis skills, such as using IDL, but she stated that she would not equate this to actually doing science. Three interviewees reported that their REU experience consisted of data reduction. One woman who had participated in two REUs stated that this "was not science. Any data monkey could do what [she] had done" during her REU. Two participants reported that they had primarily engaged in non-scientific activities during the REU. These women reported that their learning gains were a result of working in extra-curricular outreach activities, in which they engaged curriculum development and observatory tours for the public. Finally, four interviewees reported that, in the scope of their educational research experiences, their REUs were not particularly valuable. In summarizing what they learned about science during their REUs, they indicated that with regard to developing and understanding of the scientific process, it had not been an important or transformative learning experience:

- I spent the entire summer identifying galaxies. There was no science to it at all.

- Well, it didn't really make a difference for me. I didn't learn anything that I didn't already know. Same thing I learned to do in class, just different data.
- I had been given 'bad data' that he hadn't been able to analyze. I was asked to reduce it, but there was so much noise in it that there was no meaning to it. I talked to him about it, but we couldn't agree that it was pointless until the end of the summer. I don't know what I learned. [The REU] was messed up.
- You know, I can't really remember. I don't even remember [my mentor's] name…or what I did, for that matter.

Interview data agree with the findings of the previous hypothesis; analyses of the longitudinal data set and the interview data suggest that the REU, and REU-type experiences, do not provide this sample of participants with transformational, educational experiences with regard to developing an understanding of the scientific process.

Remarks

In experiences prior to the REU, participants described engaging in a continuum of education in which they were valued parts of a research community and in which they worked side-by-side with community members to develop their understanding of the scientific process. These previous experiences frequently involved individualized feedback, in which instruction from mentors formed a smooth continuum, supporting transformation in participants' understanding of the highly complex processes that constitute research. In contrast to these prior experiences, the REU provided little in the way of individual instruction. This may seem contradictory, as there is an assumption that assignment to individualized tasks might be equated with individualized instruction. However, it should be noted that individualized instruction, as described in the participants' prior experiences, requires the instructor to know students' current conceptions and provide instruction that will successfully interact with that initial state. Given the best of intentions, the astronomy REU mentor would struggle to make such assessments and adjustments for individual students, given the little available and the pre-determined nature of most REU projects. Most participants described being expected to mold themselves to a project rather than having a project selected for their talents or needs.

For most participants, the REU situated within the continuum of experiences as a repetition of what they already knew about how to engage in the scientific process, with little conflict, and little resulting transformation. Moreover, given the lack of contextual significance and the lack of a real community of practice, most participants described the REU as an inferior repetition of their previous experiences. The poor interaction between the participants' previous research experiences and the REU effectively disable what little transformational benefits that might have occurred.

Finding 3: The REU did not appear to educate participants about graduate school and did not appear to serve to enculture participants into academic science.

"In attending a liberal arts college as an undergrad, I was choosing to go to grad school."

Stage 1 Results

In Stage 1 data analysis there appeared to be some evidence that participation in the REU experience increased knowledge of graduate studies for some women. This knowledge was clustered around the related concepts of how to wisely apply to graduate school and how to succeed once admitted. According to the participants, this improvement of participants' understanding of the pathways and culture related to graduate studies was accomplished through informal means. In some years, the REU students attended an informal lunch with graduate students for about an hour, but this was an uncommon occurrence. No participant reported a seminar or other formal session related to this topic. Instead, participants' observations related to the work of graduate students, and their interactions within the various research groups served as the source of education.

With regard to graduate studies, participants indicated that they learned about graduate school by talking to graduate students at social events and by watching the interactions of the graduate students with the faculty and research staff. The interview data from the participants was rather vague with regard to specific things they learned about graduate school, and was expressed by only six participants. They reported that they "got a lot of information about graduate school," and they learned "how to get into graduate school," but struggled to describe any specifics about the nature or content of information gained. Specific learnings that can be identified were related by a small handful of women. Among these, two women who worked on a project together, stated that "schools vary in their character. Picking a mentor is much more important that which program you attend." On the other hand, they suggested that when looking for a graduate school "it's important that there are multiple people you can work with in case it doesn't work out." A second year participant, when asked specifically what she learned about choosing a graduate school, stated: "Look for happy graduate students and warm professors." These women had positive relationships with their mentor, but would have observed some less than positive relationships going on at the same time between other participants and their assigned mentors. In each year, the evaluator reported that some participants had a more positive experience than others, and this was well known to all participants as they were living and working in close quarters. It was unclear whether participants' knowledge about graduate school and relationships with mentors was gained through an intergenerational mentorship with graduate students, or through their own observations.

Responses to follow-up email surveys provided further indications of what can be considered a generationally transmitted piece of information, not likely be owned by someone without access to those who have succeeded in graduate school, whether they be parents, or mentors. That is, to consider the REU as a resume-builder: participants should make sure to emphasize this REU experience, and the faculty member you worked with, in your graduate school application. In these follow-up emails, when asked to specifically describe what they gained out of the REU experience, 44 out of the 51 participants indicated the resume-building aspect of the REU as their primary or *only* gain.

- I definitely think that having an REU under my belt helped me get into graduate school.
- It probably helped me to stand out from the other candidates for the job- not many people are able to boast that they had an internship at [a very prestigious institution] in astronomy.
- I believe that having those experiences on my resume was very beneficial, even in applying to jobs unrelated to the sciences.
- Being able to get letter of recommendation from [my mentor] was probably important in getting into graduate school.

The consistency of this response is judged to be overwhelming. As a further indication of the magnitude of this common response, the remaining seven participants either did not answer the question, or provided a non-responsive answer. It is worth noting that the participants who made specific remarks about factors that impact choosing a graduate school are among the most successful of the persisters in astronomy. Five of the six who made such comments have or are attending highly prestigious astronomy doctoral programs, working with well known advisors. Two are now engaged in high profile post-doctoral programs.

Related to success in graduate school, a few participants indicated that they had a better idea of the skill set required to succeed in graduate school. One participant stated that in graduate school "you aren't really 'on the job.' You don't show up because you're on the clock. You just show up." Another stated that being a graduate student in an astronomy program requires "lots of long workdays…figuring out stuff on your own, and learning how to ask questions in order to get what you need." In the case of this particular participant, her learning is likely credited to her relationship with her mentor. According to the participant, she frequently had to ask her mentor for information several times, with the feeling that the mentor didn't really understand what she was saying. This same participant went on to say that to do well in astronomy research one "doesn't really have to be super-smart. You just have to be persevering."

Stage 2 Results

Through analysis of the longitudinal data, evidence emerged supporting the assertion that REU experiences serve to educate participants about the culture of the academy, particularly the aspects of the academy related to graduate studies. The data from the interviews provided some disconfirming evidence for this hypothesis. During the interview participants were asked to describe their educational experiences related to astronomy and research. In their descriptions participants frequently describe situations and contexts that were rich in information related to enculturation in academic science, but none of these data were related to the REU, except in the one instance where the interviewer specifically asked about the REU and its impacts in this area. Other data were spontaneously provided and can be categorized as enculturation through the family unit or the academic year environment.

Five interviewees provided data suggesting that the family unit was a strong source of encouragement toward and enculturation in the academic sciences. These family units provided models of loved ones who had persevered through higher education and openly placed high value on an academic life.

- It was always professional science for me. My parents both went to college. They're not in the sciences, but this was always going to be it for me.
- I've always been academically oriented. My parents were passionate about their work and always told me to 'pick a job where [I'd] feel good about going to work. They were really strong models, and encouraged me to get lots of schooling. They told me not to worry about money or prestige, but to do something that I would fell passionate about, and the money would follow.
- \My mom was a professor [in the arts] and her best friend was the Dean [of Technology]. I grew up on a campus. It was my play ground.
- My parents instilled in me a drive, and confidence. They tried to make sure I knew the importance of an education and to take advantage of the education I was being offered. They emigrated from [a Soviet block country] in the 1970's so they were always telling me that in America I could become anything I wanted to be. This was really important to them…. They weren't scientists but the definitely encouraged an interest in science. They would always tell me: "You can do anything."
- Everyone in my family was interested in science and technology. My grandfather was an early computer guy, and my great-grandmother studied astronomy at [an Ivy League school]. My great aunt had a PhD in computer programming…. My grandfather always said that the women were the educated ones in the family.

Five interviewees also indicated that their academic year environments were primary sources of enculturation. These contexts were rich in daily examples of the structure of the academy and the pathways through that hierarchy. Perhaps more importantly, as these women engaged with these environments, their identification with the culture of astronomy research increased, while they increasingly adopted the social mores of that culture. The one participant who attended a small, liberal arts college stated:

> In attending a liberal arts college as an undergrad, I was choosing to go to grad school. [My college] was focused on higher education. Hardly anybody takes jobs

> directly out of [my college]. Everyone goes to grad school…. The question wasn't: "What are you going to do after you get out?" It was: "Where are you going to go?"

Others indicated that a faculty member explicitly assisted them in finding their way through the academic system:

> My mentor became my unofficial advisor. When I needed to know which courses I should take next, or which schools I should apply to, she was the one I would talk to.

Finally, four participants provided data suggesting that they were housed in academic departments where graduate studies were not only expected, but a constant topic of conversation. As reported by one participant, these women:

> picked up knowledge about graduate school and becoming a professor through of interactions with astronomers and the academics. It was just years of being in the system.

Out of the eight interview participants, only one described the REU as having an important relationship to graduate studies. When asked what function the REU played in her thoughts related to graduate school, this participant reported that when she began graduate school, she found that all of the other graduate students had also participated in REUs. From this information she concluded, *ex post facto*, that having an REU on one's resume must be an important part of a successful graduate school application in astronomy. She did not provide other information indicating that the REU had been informative with regard to success in entering or completing graduate school.

In the analysis of these data, statements from this outlier in the data set were sufficiently curious as to merit another look at the interview data. This tertiary review indicated that in the interviewer had explicitly asked this one participant if "the REU was an important source of information about grad school." The other participants did not receive this explicit prompt, and did not spontaneously provide data supporting this finding. It appeared as if this data provided by this one participant might actually be an artifact of the interviewer's direct questioning.

The possibility that an interview protocol may have unintentionally encouraged a false positive result led to a tertiary review of the Stage 1 longitudinal data, as well. In that data set a similar pattern was found. In years where the original evaluator(s) specifically asked participants if they had learned anything about graduate school, there were some participants who provided data indicating that they had some small learning gains, as described in the first section of this chapter. (Refer to the first section of this chapter, in the subsection titled: "Developing an understanding of the culture of academia.") In years where questions about graduate school were absent from the evaluation protocol, no students spontaneously volunteered that they had learning gains related to graduate school. Given that participants frequently volunteered information going well beyond the scope of the evaluation prompt, it seems reasonable to assert that they should have also provided data related to the ability of the REU to educate about graduate school, if the REU were functioning in this capacity. In the same manner, the eight interview participants frequently provided information that was unexpected, venturing far outside the scope of the interview questions. In no case did participants voluntarily mention that the REU played a role in developing their understanding of the academy. These reviews of the data suggest that the data describing the REU as having an educational functional with regard to graduate school, are suspect. Such data points are most likely artifacts of leading interview questions on the parts of the original evaluation and research protocols.

In the end, this study provides no reliable evidence to suggest that the REU functions to educate these women about, or enculturate them into the academy, in a meaningful or consistent manner.

Remarks

Clearly, participants' prior experiences provided a rich, educational continuum related to academic endeavors. This continuum frequently began in the elementary years and continued on into the undergraduate years. This resulted in all participants entering the REU with a wealth of information related to graduate school and the tasks associated with success in the academic world. The REU did not appear to interact with this continuum in a negative way, but interacted with this continuum as a repeat of previous education. There was little indication that the REU interacted with prior experiences in such a way as to extend or explicate previous learnings. Therefore, there was little in the way of transformation in this area. Working in a Dewey framework, the REU would not be considered educational in this domain.

Finding 4: Participants appeared to enter the REU with strong identities as related to the "self" and to science, which the REU did not appear to transform.

"I've always known I wanted to be a scientist."

Stage 1 Results

The final category relates to the participants' transformations, with regard to an understanding of themselves, as situated in science, or in the broader scope of their lives. In this case, the notion of transformation is more difficult to detect. It is rather easy for a student to articulate that they have learned about graduate school. It is much more difficult to be aware of and articulate that one has transformed as an individual. Therefore, it was necessary to analyze the data through two lenses: through direct analysis of participants' comments, and through a comparison of participants' comments prior to the REU, after the REU, and what they were saying years later. Analysis of these data indicate that the REU had little transformational power with regard to these women situating themselves within science, and specifically astronomy. Transformations or insights related to the personal self were limited to few women and were small in scope.

From the data gathered through beginning-of-the-summer interviews, participants entered the REU with strong science oriented identities. With one exception, participants indicated that they had been attracted to, or had "known" that they would go into science since well before entering college:

- I've wanted to be an astronomer since before high school.
- I've always wanted to do something in space. Even as a small child, I wanted to do something in space, like be an astronaut, and astronomy is pretty close. I've always been a science nerd.

- I've always known I wanted to be a scientist. I can remember being, like six, being inquisitive.

Many of these early associations with science and astronomy were linked to early memories of engaging in science activities with family members. These memories included:

- Receiving Radio Shack crystal radio kits for Christmas from grandparents,
- Looking through telescopes with a father, and
- Watching a shuttle launch in the classroom of a favorite teacher.

There was no evidence to suggest that anything occurred over the course of these summer research experiences to dissuade any of the participants from this path. This was true even in the face of low quality, and occasionally miserable, REUs. (This will be discussed at length in the next subsection.)

The strength of this observation is enhanced by analyzing the current activities of participants, some as far as eight years beyond their REU summer. If one broadens the definition of the science career pipeline beyond the parameters of the academy, all participants in which there are valid data are still engaged in science, math, or technology. (One participant experienced a personal tragedy that derailed her career path, and is therefore not considered informative in this analysis.) Those who have not persisted in an astronomy field have moved into closely related STEM fields, such as science education, medicine, and information analysis. However, it cannot be said that the REU impacted participants in such a way that they became more inclined to engage in science career fields; they were science-inclined before entering the program. It can be said that there is no obvious evidence that the REU discouraged participants from engaging in the STEM fields, or that they were discouraged enough to actually exit STEM. In other words, this study does not provide evidence suggesting that the REU functioned to transform participants such that they identify themselves more closely with science, but it does not appear to have had the opposite effect, either.

Indeed, in terms of situating themselves either within or outside of science and astronomy, the REU seems to have only functioned as a slight refining experience. At the end-of-summer interview, only four out of the 51 participants described the REU as having an impact on their intention to enter graduate school in either astronomy or physics, with one deciding that she would chose astronomy, two stating that the summer had persuaded them to pursue physics instead, and one stating that she had decided to follow a course outside of astronomy. In the cases of the two women who decided to opt out of astronomy, the data collected could best be described as "polite." As one woman said:

> The problems in astronomy are interesting and very important. They're just not that interesting to me. I don't feel passionate about it. I think I'm going to do theoretical physics, or a combination of physics and philosophy.

For the woman who decided to opt out of both fields she decided "not to go to grad school in astro or physics because it's mostly computer work." The summer helped her to understand these fields better, and to realize that they did not match the lifestyle she desired. However, comparisons of this data to beginning-of-summer interviews indicate that these women displayed ambivalence towards a career in research astronomy prior to beginning their REU. For instance, one participant stated:

> I'm not really sure that I want to go into astronomy on the research side, but I don't want to just dismiss it. I want to give it a try.

At the end of summer, this participant reported that she intended to follow a career path in engineering. In short, there were very few women who reported that the experience was strongly influential, let alone transforming, as related to their intended career pathways.

For some participants, the REU was a chance to further explore subtopics in astronomy. A few participants reported that they were now leaning toward topics such as astrobiology, astrophysics, solar physics, observational astronomy, or "anything in astronomy except doing observations." One participant explained that while she had always known that she wanted to go into astronomy, she was "using REUs to explore a variety of topics so that [she] can know what to study in graduate school." However, when the data from the most recent alumni surveys were analyzed, there appeared to be no relationship between either the REU research topic, or the end-of-summer leanings toward a subtopic, and what subtopics participants are currently pursuing.

Other participants reported that they had engaged in the REU in order to gain insight into the direction their career should take, without success. One participant reported that she wanted to do an REU to find out whether she wanted to go into astronomy or medical physics, but had not decided based on her experience. Another participant who came into the program without a life-long interest in astronomy left without increased insight:

> I came to the REU to figure out why I'm doing astronomy. I still don't know why I'm doing this.

In addition, a few participants learned about their own work and learning needs. In three cases participants gave statements that explicitly indicated their slightly increased awareness of themselves. One woman stated:

> I couldn't work like that. I can't work in a bullpen of cubicles. I need a quiet place to be productive.

Another woman found that she was not successful over the course of the summer as her mentor took too much of a *laissez faire* approach to their project's management.

> Sometimes I felt lost. I didn't know what I was doing, or what I should be doing for the day, and was worried that [my mentor] would think I was a slacker. ... I think that I probably need a little more of an omnipresent mentor. If nothing else, I would know if I was on-track and I wouldn't be so stressed out. Then I might actually be able to get more work done. ... I think when I'm in graduate school I'm going to look for a more hands-on advisor.

Finally, one participant stated that the summer had "finally" taught her how to balance her life and her work. In the past she had struggled with either achieving balance, or recognizing that balance. Her experiences over the summer helped her to learn how to "work hard, accomplish goals, and play hard." For this particular participant this could be considered to be a meaningful transformation, although unrelated to the larger goals of the program.

Stage 2 Results

Throughout analysis of the longitudinal data, the evidence suggested that REU experiences do not serve to transform participants' conceptions about themselves as situated in science and astronomy, and learning gains with regard to other aspects of the self, were somewhat limited. The data from the interviews provide no disconfirming evidence contradicting this hypothesis. Instead, the interview data provide even further evidence that the women who participated in the study arrived at the REU with pre-existing and remarkably strong senses of self, and that the REU did not functional to alter those states.

With regard to situating themselves in STEM, these women confirmed the evidence in the longitudinal data. Without exception these women state that they have "always" wanted to engage in astronomy, science, or engineering. Two of the women stated that they had wanted to engage in astronomy since early childhood.

- It was always astronomy for me. Since about elementary school. I would read just about everything, but my favorite was this kids' science magazine, and they had these articles on astronomy. Those were my favorite articles.
- I always wanted to do astronomy. I can remember as a kid that my favorite books were the ones on space. … Black holes, whatever. I just wanted to do that.

Three stated a more general interest in science that began to focus on astronomy during the high school years.

- From a very young age I was interested in science. I didn't differentiate much between them. I went to all kinds of summer camps, whatever they had for science. … I knew I wanted to be a scientist in 1st grade. I would mix my lunch food together to see if I could get a chemical reaction. Since 1st grade I was doing things like that. … I remember when I was six, we went to the planetarium, and I remember thinking: "Wow! This stuff is cool!" … And I liked math. We do a lot of math in astronomy so it feeds that interest as well. … I knew I wanted to be a scientist since about 5th grade. (Note: This participant was actively engaged in research at an observatory by the time she was in 9th grade.)
- Why did I choose science? … I remember that from kindergarten to 2nd grade I was in [an extracurricular program], but that got really boring, so my parents enrolled me in [a different program]. In that program you can choose what you want to study. You could choose anything you want, and

I always choose science and math classes. I did that from about 3rd grade until I graduated high school.

- I had been interested in science, and interested in astronomy, but I didn't know how much until I attended the Summer Science Program. I learned a lot there. …. And I had a peer group, finally! I enjoyed these people, and I enjoyed doing [astronomy] and it's not crazy. … These were my peers, and this is what I wanted to do, and I haven't looked back since.

Two stated that their interest had been in mathematics.

- I can remember that when we were riding in the car, I had math work books instead of coloring books. My dad would get them for me, and I think I liked them more that the coloring books. Solving problems is fun to me. … In high school I was always good at science. And I read books about science, like Stephen Hawkings' "Brief History of Time." … I had fun solving problems, like in physics.
- I've always loved math and working through things. But I didn't like math class until 8th grade. … When I was in 5th grade, my teacher told me that I had made him completely revise the way he taught math, because he had always just presented the information and had kids do [the math]. But I was always asking him: "Why?" I hate memorization. … In 8th grade I was put into an accelerated math course and that was amazing. We were given hard problems to work; the answers weren't obvious. And you really had to think through them. … That's the kind of thing I enjoy. … I didn't like science because it was all memorization, until I was in 9th grade. I had a teacher, who was new, for general science. He kind of threw away the textbook and instead, would come in everyday with a new demonstration that he would show us. It was our job to figure out and journal about what we were seeing; why was it happening. It was a completely new way of thinking about science. No memorization, just logic, and I loved that. I'd say that's when I knew that I wanted to be a scientist.

One described an early interest in engineering:

> I decided I wanted to become an engineer when I was about 11 years old. …I took engineering classes in high school. We had just moved and the new school had an engineering magnet in it. We moved in about half way through the school year and they said that I couldn't join the magnet, because you could only join at the beginning of the year. So, I asked them: "Why not?" They said that they had been learning to use a computer program since the beginning of the school year, and I didn't know it. So I told them to give it to

> me over Christmas Break, and I would know it by the time we got back to school. … I mean, I was the only kid who actually wanted to be in the program and they were trying to stop me. All of the other kids were there because their parents made them, or some teacher thought they were gifted, but I wanted to be there. … That program gave me lots of support. It was like: "I like engineering," and the program would let me know that it was a cool thing to do. …. I mean, I've had teachers who told me I couldn't do it, and I ignored them. And sometimes I would ask people if they wanted to see something that I'd built, and they would say "No." So I would just say: "Well that's OK, because I'm only showing the cool people, and you aren't cool." [Laughs.] No matter what anyone said, this has always been what I've wanted to do. So I'm doing it. … I'm carving out my path.

At this time, the seven women who had very early interests in astronomy, science, and math have either earned a doctorate in astronomy, or are close to completing that work. The woman who wanted to be an engineer since she was eleven is currently completing her doctoral work in engineering.

The data indicate that these self-images have developed in the presences of both encouraging and discouraging pressures. Much of this section has been devoted to describing the family members, mentors and programs that have supported these women since childhood, and that have assisted them in forming self-images that situate them in STEM. Other data suggest that these women have maintained these self-images *despite* family members, research mentors and programs that should have functioned to dissuade them from the paths they have chosen. Some of these women had family members discourage their academic interest, either through neglect or active opposition:

- I've thoughts about other paths, but it always comes back to this for me. I've always wanted to know how the universe works, and I wanted to be at the forefront of that. I don't want to be one of those people who take up some small part of the work after the people on the edge have already answered all of the important questions. … And I've always thought "I don't want to be my parents." I don't want to just get a paycheck. I mean they have jobs, but that's all it is. I want more. … No, graduate school and getting a PhD is something they neither encourage nor understand, especially in something like astronomy. They never checked my report cards. They didn't help with homework or anything. … The most important factor in how I got here? My parents. I don't want to be my parents.

- My parents were upset with me when I took the research job in astronomy. In their minds it was a waste when I could have been getting other experience. They said "There's no jobs in astronomy." And I should be doing something else. Taking the [summer job in astronomy] was the first decision I'd made contrary to my parents.

All participants reported receiving at least some discouraging messages from either faculty or researchers. At the high school level, one teacher discouraged a participant from research in the field:

> When we were doing our projects my teacher wasn't very helpful. She'd say: "You can't win a science fair doing astronomy research," because astronomy doesn't lend itself to the typical "hypothesis scientific method."

Other participants were discouraged from taking accelerated courses in science and mathematics, as those courses are "more work than [the participant] would want to have to do." Researchers, at REUs and at home institutions, told participants that they should go into other fields besides astronomy. Their stated reasons related to the small number of jobs in the field and the long hours involved in earning tenure. Other faculty members are reported to have, ironically, tried to dissuade participants from entering the field by telling them that astronomy is not welcoming to women. These faculty members pointed out that many of the most prominent women in astronomy are unmarried and/or do not have children, and that women who desire a family life will not do well in the field, a generationally transmitted idea that may be something of a self-fulfilling prophecy.

This seems relatively common as women being interviewed spontaneously described that when they sought out assistance from home institution faculty and course instructors, they were occasionally counseled that the act of requesting help was an indicator that they do not belong in the field. Commonly reported statements such as "If you can't get this without coming to me then you're wasting your money taking this class," and "You know, some of you just don't belong here," do not merely serve to deny students the help that they need to be successful; they serve to reduce a student's sense of self-confidence and belonging. In summary, all participants received both subtle and pointed messages that they should not pursue their chosen fields; nonetheless, these women were not dissuaded.

In the course of the interviews, participants provided no data, explicit or inferred, indicating that the REU served as a variable in the establishment of their identities within STEM, in any direction. During the course of over ten hours of interview data describing themselves in the sciences, none of the participants mentioned the REU as impacting the ways in which they situated themselves within the sciences. Whether experiences during an REU were depicted as either positive or negative, they appeared to lack transformational power. In no case was an REU experience cited as an important experience when participants were asked to describe the factors that have converged to form their identities. This stands in stark contrast to the many transformative experiences that were spontaneously described by participants.

At the end of each interview, in the absence of spontaneous utterances related to the transformational nature of the REU, the interviewer went on to purposefully and specifically ask each participant how they would be different if they had not attended their REUs. Their responses indicate that an omission of the REU would have little impact of their current sense of identity in STEM:

- Well, I don't know that it would make a difference.
- If I hadn't gone to the REU [at a specific observatory], I wouldn't know that I [wouldn't like living there.]
- With the REU I was playing with an identity to see if it fits me as well as I think it would. It was on about the same level as doing Science Olympiad in high school.
- I confirmed for me that engineering is what I want to do. …. But I had known that already.
- If I hadn't gone, to the second [REU], I wouldn't have gotten to see [the local tourist sites].
- It was good for variety, and I got to do a different topic of research. But, if I hadn't done it, I would have just done something else.
- I think that I was allowed to see new cultures through my REUs. I'm probably more likely to travel now than I was before.
- I could do observing in [my undergraduate location]. And if it was about getting to interact with astronomers, I had plenty of those at [my home department]. If anything, if I hadn't gotten in I'd still be more determined. I'd be more driven to show them that I could do [astronomy]. I'd have done some other program. … It was fun, but it didn't influence me. I'd still be an astronomer.

Remarks

Participants' construction of their sense of self was a result of over twenty years of continuously interacting educational, transformational experiences. In order for the REU to provide a meaningful transformation experience in this domain, it would need to interact with that prior continuum as a contradiction to, or extension of, that pre-existing identity construction. Given the strength of the participants' sense of self at the time that they entered the REU, it is unreasonable to believe that the REU could noticeably alter that prior state in just 10 weeks. As participants repeatedly described, they entered the REU with long-held conceptions of themselves as belonging in STEM. Given the strength of participants' sense of self, there was little the REU could provide to make participants' doubt that prior construction. Not only would such an experience be destructive, and therefore not educational in a Dewey framework, but that experience would have to counteract a great deal: twenty years of experiences that indicate that the participant belonged in the scientific community, external messages from valued individuals who contributed to the conception of self as scientist, and internal dialogue that agreed with, and synthesized those inputs. Fortunately, the REU lacked the power to interact with any participants in this way. Similarly, there is little benefit that the REU could contribute other than to confirm what the participant already knew. While the REU did not appear to damage the participants' sense of self, it did not appear to make substantial contributions.

The Impacts of the Participant/Mentor Relationship and the Quality of the REU

This subsection describes observations made with regard to how the participant/mentor relationship and the quality of the REU experience impact the educational function of the REU. Common wisdom would suggest that the nature or quality of the REU experience would be an influential cross-cutting category within the data set. However, an extensive search for such an axial correlation between the nature of the REU experience and educational outcomes was unsuccessful. Instead, the data suggest that for the women who participated in astronomy REUs, the quality of their REU and their learning outcomes are unrelated.

Over the span of the eight years of data, there was an extraordinary range in participant/mentor relationships. These relationships varied in structure (i.e.: the hours spent together, frequency of meeting, modes of communication, etc.) and character (i.e.: the extent to which the participants and mentors collaborated harmoniously and productively). There were relationships in which the mentor was geographically on a different continent for the majority of the summer during the REU, those in which the mentor was physically nearby but not available to meet or support the student, and those in which the participant and mentor shared an office space thereby interacting on a daily basis. Some relationships began with emails sent out by the mentor well in advance of the actual REU start dates, some in which email or Skype was the primary mode of communication throughout the entirety of the experience, and those in which the mentor completely was out of communication in addition to being physically absent. In some relationships there was a close work collaboration, in which the mentor showed genuine interest in the daily work of the project, and others in which the mentor was alarmingly inattentive. This is consistent with a wide range of experiences reported elsewhere (Guterman 2007).

The data give clear evidence that participants value the presence of the mentor. While graduate students are more readily accessible, regular and meaningful face-to-face time with a real astronomer is valued more by REU participants than having unlimited time and access with the astronomer’s graduate students or post-docs. This is true even when these individuals are more knowledgeable about the research project than the mentor is. Moreover, this is true even when participants chose to go to graduate students for assistance:

> The [graduate assistant] was really helpful. I know that I could have gone to my mentor for help with my questions, but I pretty much always asked [the graduate assistant]...so I wouldn't look dumb.

There were occasions when participants stated that an absentee mentor was acceptable, indicating that the mentor "staying out of the way" allowed work to progress. But, there were no occasions on which participants indicated that they suffered from an overly attentive mentor.

There was also wide variation in the character of these relationships. In a few instances participants described the generosity of a mentor. They related that mentors arranged for additional observing runs for participants, invited them into their homes, and asked them to join them in extracurricular activities. Some mentors loaned participants bicycles and household goods while they were on site, and in one case a faculty member opened their home and allowed participants to stay there during their REU. Some participants spoke of their mentors in fairly glowing terms, while some seem to truly loathe the mentor who oversaw their project. Women state that, at times, mentors and participants nearly came to blows over perceived slights, as often on the mentor's side as the participant's. At other times the relationships were derailed by differences in cultures, and by accents. The evaluator's field notes repeatedly show that mentors were offended by the lack of skill some participants possessed at the beginning of the summer, and clearly resented the impediment this represented to the project. Some participants began the summer with such an abundance of confidence in their own skills that mentors had difficulty teaching them.

> There was a real barrier to helping [my student] to move forward. At times it seemed as if she knew everything already, and didn't see that she had much to learn here.

On multiple occasions participants were reassigned to new mentors, either due to the mentors' absence, or to other cause. In one instance the mentor left midsummer to enter an addiction treatment center. In a different instance a working relationship was cut short when the mentor/student took an inappropriate turn.. In other words, the same kindnesses and insults that play out in everyday life, also play out in the REU environment. The same agreements and clashes that occur between any two human beings, occur between participants and mentors.

The quality of participants' REU experience can best be defined by their own perceptions. Again, there is an extraordinary range of experiences, as indicated in participants comments related to the program structure and their research experience. For some, attending this particular REU was "a dream come true." They reported that their expectation of being able to see a "beautiful, exotic location where some of the world's most advanced telescopes" are situated, was fulfilled. They enjoyed the activities that were available to them, appreciated the house that was provided *gratis*, and expressed gratitude for the administrator who arranged their flights and the colloquia. Some participants spoke at length regarding the high quality of their observation run, and appeared to be truly moved at the opportunity to observe at one of the premier locations on the planet.

- This is it. My advisor at [my home institution] would love to be out here. This is the best. I've been waiting my whole life to do this.
- We didn't actually get to operate the telescope ourselves, but I was still there. I was...amazing.
- Well, yeah. Come on. I had about three places to choose from, And, of course, I picked here. [laughs]

Others stated that the REU had been "a waste of a summer." They were dismayed by the isolated location, both in terms of being "island bound" and in terms of where their accommodations were located. Some complained that they could not enjoy any activities due to a lack of transportation and that they were asked to "live like a freshman in the dorms." Other participants truly appeared to struggle with the number of "bugs" present in a tropical location. Several of the women were disappointed by what they perceived to be the lack of organization in the program, and one participant felt that they should have been paid more for the summer, or had their medical insurance covered. With regard to observing, cloud cover cancelled some observations, and some participants were made ill by altitude at the observatory, including one woman who passed out and hit her head and had to be taken to the hospital. Between the extremes of "a dream come true" and "a waste of a summer" there were many intermediate perceptions of the REU experience as described by the participants.

A purposeful analysis attempting to discern correlations between the educational impact of the REU, and either the participant/mentor relationship or the quality of the REU experience was unsuccessful. The first finding related to the nature of the work of astronomy, is based in data that present consistently across the sample population. Many students became increasingly aware that the work of astronomy involves a great deal of computer work and coding. This became clear for students regardless of the nature of their mentor relationship or the richness of their REU experience. Similarly, across the population, participants did not report increases in their understanding of the scientific process, either directly or indirectly. The third and fourth findings surfaced inconsistently across the sample, with less than a quarter describing insights into either graduate studies or into themselves as scientists and individuals. An attempt was made to discern if these few reports clustered around individuals who shared similar types of REU experiences. No relationship was found. Participants who reported enhanced understanding of graduate studies reported mentor relationships across the spectrum. Some of these participants reported high quality REU experiences, and others in this group reported very low quality experiences. Again, there was no discernable relationship. The same result was found in when analyzing the data related to personal insights. From this eight -year sample it was not possible to detect evidence that "good" REU experiences have more educational impact than "bad" REU experiences.

Ranking the factors that served as educational experiences for the participants

As a final attempt to elicit information related to educational transformations, interview participants were asked to rank the experiences that they had related, which served an educational function on their pathways through STEM. This final question in the interview followed a consistent and carefully constructed protocol.:

> Prompt 1:
> Researcher: So, in our conversation you've described a large set of experiences that you've had. In order to help me get a sense of how these experiences situate themselves within the whole of your experiences, could you tell me: which of the

> experiences has been most important to you? Which of the experiences does the best job of explaining where you are, who you've turned out to be, what made you become what you've become, what you know in science…however you choose your Number 1, that's up to you, because we'll talk about it so that you can explain what you're thinking.
>
> <u>Prompt 2:</u>
> Researcher: Now, if I were to give you a second choice, the second most influential educational experience in your long journey to where you are, what would it be? (And, again, you'll get a chance to explain what you're thinking.)
>
> <u>Prompt 3:</u>
> Researcher: Alright. What if we take it from the other direction? What educational experiences have been least important? For instance, if your life was a movie, and you could use a video editing program to delete a scene or two, which of these experiences could you delete without changing the outcome? If you could toss out one or two of your experiences and still be where you are now, doing what you're doing, which would it be? (Again, there will be a chance to explain.)

In all cases, responses served to reframe or summarize the contents of the interviews. No participant reported that an REU, or REU-type program, served as an important transformational, educational, or influential experience. Instead, when asked to select the one or two experiences that most accounted for their pathway through STEM, three participants cited high school level courses and non-REU summer programs, three interviewees cited experiences with parents or family figures, and two participants cited three-year long research relationships with undergraduate mentors. Participants were then asked to select the one or two experiences that could be deleted from their personal histories without impacting their education or STEM trajectory. All eight participants unequivocally cited REUs or REU-type experiences, including an 8-week summer internship in industry that shared many of the attributes of the REU. Some of these REUs occurred at the institution associated with the longitudinal data described in the first section of this chapter. Other REUs and REU-type experiences occurred at three other locations. These data are listed in Table 5.

Table 5

Most and least important experiences, as perceived by participants

Participant	Most important experience(s)	Least important experience(s)
A	• High school science course	• REU (other institution) • REU (studied institution)
B	• High school work with amateur astronomy club	• REU (studied institution)
C	• Summer RSI program • High school work at local observatory	• REU (studied institution) • REU-type experience (Europe)
D	• My parents (positive response)	• REU (studied institution)
E	• My parents (negative response)	• REU (studied institution)
F	• Mother's best friend • Undergraduate astronomy course (home institution)	• REU-type experience in industry • REU (studied institution)
G	• Undergraduate research facilitated by mentor (home institution)	• REU (other institution) • REU (studied institution)
H	• Undergraduate research directed by mentor (home institution)	• REU (studied institution)

These data do not indicate that the REU experience was truly the least valuable educational experience within the entirety of each participant's continuous education. Rather, it can be asserted that these data indicate that the REU was consistently considered less valuable than other educational experiences. When allowed to place the REU experience within the larger context of their lives these participants judged the REU to be the most expendable of many educational experiences. In the continuum of their educations, the REU was judged to be of less importance than a high school science course, a family friend, a high school summer program, or an undergraduate mentor.

Summary of Results

Data were collected to address these research questions in two stages. First, longitudinal data were collected over an eight year period. These data consisted of participant and faculty interviews over the course of their summer in the program, and yearly follow up interviews and surveys. Additional analyzed data were collected through interviews or surveys with mentors, and in the extensive external evaluator's field notes. These data were inductively coded and categorized, and revealed four findings: (i) while some participants indicated that they came to understand astronomy as a computer-dominated endeavor, participants did not describe content-knowledge gains in astronomy, (ii) participants did not describe an increased understanding of the scientific process as a result of the REU, (iii) the REU did not appear to educate participants about graduate school and did not appear to serve to enculture participants into academic science, and (iv) participants appeared to enter the REU with strong identities as related to the “self” and to science, which the REU did not appear to transform. Data were then purposefully collected through one-hour interviews with eight participants in an attempt to disconfirm or refine findings, in Stage 2. Interview subjects were purposefully chosen for their potential to provide this disconfirming/refining data.

The findings are that the REU experience itself is providing little in the way of an educational or transformational experience for these women. The category in which the data indicate some limited transformation is in regard to participants’ enhanced understanding of the work of professional astronomy. Longitudinal data indicate that ten of the 51 participants increased their understanding of astronomy as computer based work. In Stage 2, three of the eight participants indicated that the REU provided them with this same insight into the work of astronomy. Therefore, the interviews in Stage 2 confirm the finding: for a small portion of these women, the REU helped them to develop their understanding of the computer-based nature of astronomy research.

With regard to developing an understanding of the scientific process, both longitudinal and Stage 2 interviews indicate that the REU did not function to transform these women’s understanding of the work of science. Therefore, the overall analysis suggests that the REUs are not a meaningful educational experience with regard to the scientific process when these participants look back at their experience within the context of their educational experiences.

With regard to enculturation in the academy, initial analysis of longitudinal data suggested that the REU may possess some educational value with regard to participants’ knowledge of graduate school. Further analysis suggests that these data points may be an artifact of the data collection protocol. Stage 2 interviews found no evidence of the REU's transformational power in this domain. Instead, the interviews suggest that, in the scope of the participants' broader experiences, the REU makes a very limited contribution to the knowledge of and enculturation into academic astronomy for these women.

With regard to the participants' perceptions of themselves within astronomy and the sciences in general, or of themselves as individuals, the longitudinal data suggest that these women were firmly grounded in the STEM fields, particularly in astronomy, well prior to their REU experiences. Within the longitudinal data there was some indication that the REU might inform the choice of subfield, or an understanding of the individual's work habits, but the transformations appeared to be rather minimal and the supporting evidence was weak at best. In Stage 2 interviews it appeared that the REU has little or no power to transform the participants in term of their situation within astronomy or STEM, confirming the analysis of longitudinal data. Stage 2 data indicated that the REU had little or no influence on the choice of subfield, nor did it appear to provide transformational experiences with regard to the self. This study suggests that REUs, and REU-type experiences do not transform these participants' understanding of themselves, or their position within STEM, but that the rich prior experiences of participants interacted with the REU to diminish its educational impact.

The implications of these results will be discussed in Chapter 5.

CHAPTER 5: DISCUSSION

This chapter provides conclusions and literature based perspectives related to determining the educational nature of an astronomy REU experience, as perceived by participants. Whereas the previous chapters separated the study results by data collection and analysis method, this chapter first presents a summary of the results, followed by a brief response to the research questions. This will be followed by a presentation of holistic interpretations of these data in the form of three overarching conclusions. The chapter concludes with implications emerging from the study for future programs and proposes future research questions as yet unanswered.

Response to the Research Questions

This section provides a very brief response to the research questions. This will be followed by conclusions that both expand upon those responses, and relate the responses to the larger bodies of literature that provide structure to the study's findings.

Sub-Question 1

What were the experiences of women in an astronomy REU, and what educational role did the REU play in their development?

(1) In what ways does the REU serve to interact with the continuum of participants' other life and educational experiences? Is the REU serving to provide educational experiences that reinforce previous learning or does it make a unique contribution? How does the REU experience situate within the larger context of participants' experiences? What is the magnitude of educational power of the REU experience, as situated within the larger field of participants' other educational experiences?

The REU does not appear to provide a unique educational experience for women who participated in the program, and essentially disappears from the educational landscape when situated within the broader context of participants' experiences. The most powerful evidence for this assertion is that when asked to rank the many factors that served an educational function on their pathways through STEM, no participants ranked the REU as the most important. On the contrary, all participants ranked REUs, whether at this study site or at another location, as the least important educational experiences in their training within STEM, as compared to the many other experiences cited.

The data suggest that the participants in this REU program were an academically accomplished group. They collectively possessed a wide array of previous academic and research experiences. As suggested by Dewey, these prior experiences were not left at the door when the participants entered their REU; rather, those experiences were continuous with the REU, interacting with that experience in such a way as to diminish its transformational potential. It is possible that the REU served to reinforce previous learnings, by serving as a metacognitive prompt. Participants were able to compare their REUs to more powerfully transformative experiences, and through that comparison, identify specifically meaningful elements in those experiences. However, in the larger educational landscape, the REU only provided a unique educational experience for the few who came to understand that astronomy is largely a computer-mediated endeavor. The data indicate that the participants with little or no prior research experience were the only individuals to report this as a learning outcome. Further, this transformation was only described as being valuable by two out of 51 participants. Situated within the larger context of rich prior and subsequent experiences, the REU provided little in the way of a transformational experience.

Sub-question 2

What were the experiences of women in an astronomy REU, and what educational role did the REU play in their development?

(2) In what ways, if any, does the REU function as an transformative educational experience? In what ways does it change the ways in which these women think about the work of science and astronomy? In what ways, if any, do REUs change the ways in which these women think about themselves, in relation to the field of astronomy, the work of science, or in terms of their knowledge of self?

As indicated in the previous section, data from this study suggests that the REU has an educational, transformative power for only small portion of women in the study, and that transformation is limited to their understanding of the daily work of astronomy as a largely computer-based endeavor. This sole learning outcome is small in dimension, and is accomplished implicitly through tasks assigned to the participants. This study provides evidence to suggest that the REU does not have important impacts on participants' conceptions of the scientific process, the culture of academic astronomy, or of themselves. In fact, there is some evidence to suggest that the REU has little or no impact in these areas.

Conclusions

Conclusion 1: When taking a long-term, reflective view of their science education, a significant group of women in astronomy identify a multitude of important life experiences and individuals that contributed to their education as astronomers, but REU-type experiences are not identified. This is true whether considering education related to content, skills, the sub-culture of astronomy, or knowledge of themselves.

In eight years of longitudinal data, and over ten hours of interview data, there was little evidence to suggest that the participants considered the REU to be of educational value. The author acknowledges that this conclusion is in conflict with studies and evaluations conducted while participants are still working toward, and even through, graduate studies. However, when giving exit interviews at the end of a summer REU program, participants have little reason to critique the substance of a program beyond structural issues of quality of housing, frequency of social interactions, and nature of their physical work space. One could reasonably argue that there exist great disincentives to providing any criticism at all because they are hoping to obtain positive letters of recommendation for graduate school from their supervisors, regardless of how carefully anonymity is guaranteed. In this study, where women were provided with multiple, open-ended opportunities to share their perspective on their REU, with a trusted interviewer, and well after applying to graduate school, a different story emerged.

A position one might take is that most of these young participants, still early in their scientific training, may lack some degree of the discernment earned by spending time in the STEM career pipeline that would allow them to provide strong insight into the value of the REU. Yet, the interviews conducted with participants years after the REU indicate that these women have a high degree of expertise and possess much hard-earned wisdom. Years after their various educational experiences, they are able to describe those experiences, including the nature of the work and the relationships relevant to those experiences, in detail. They are able to clearly articulate which experiences and relationships they found valuable in steering their pathway through the STEM pipeline. Given their host of experiences, they are judged to be well qualified to make judgments about the quality of their REU experience(s). They judged the REU programs that they attended to be, for the most part, irrelevant in their education.

The most compelling data in this, or arguably any of the studies related to REU completed thus far, were collected during interview with participants. During these interviews, from one to eight years after participation, participants provided extended and rich descriptions of the experiences they characterize as shaping their identity as a scientist and pathways they followed. In no case, do they ever spontaneously mention the REU. More to the point, at the end of the interviews when they are asked to choose the least important of the educational experiences described, all eight pointedly said that the REU could be removed from their list of experiences without negative impacts. While the exotic location, generous pay and resume-building qualities of the REUs were appreciated by most participants, the REU was, as described by several participants , a high-paying, prestigious “summer job.” The audience for this study should not confused participants’ appreciation with the belief that the REU was an important educational experience. The participants themselves do not appear to be confused about the difference.

This conclusion agrees with theory put forth by Dewey, in which he suggests that the value of an educational experience arises from the continuity of that experience with those that have come before and will come after, and interaction between those many experiences. In the case of this study, the data suggest that the rich prior experiences of the participants, served to make the REU largely irrelevant in terms of educational value. There was no evidence that this conclusion is related to the quality of the REU experience or the intentions of the REU faculty, staff or funders. Instead, it seems that the programs competitive application process resulted in a group of participants that already possessed such a strong resume of experiences that the REU could only pale in comparison to all that had come before and would follow after.

It is possible that the preferred structures in the REU are a hindrance to achieving the programs stated goal of providing an important educational experience for women in astronomy. The majority of scientists and students engaged in the program want to be involved in real research where the end result is a published paper with shared authorship. Yet, most research studies have a tenure extending far beyond the REU's 10-week duration. As a result, students are plugged into an existing program where they enter and exit at meaningless junctures and have highly constrained engagement into the questions, design, or conclusions. It is possible that a collective goal to have a published paper interferes with students actually doing science during the summer. Consistent with this, the annual evaluation reports repeatedly confirm that REU students are largely unable to articulate the larger context of their individual research project in any sort of meaningful way. At the same time, future scientists desperately need to have authentic research experiences somewhere in their undergraduate experience, where they participate in the scientific enterprise by formulating questions, designing strategies to pursue evidence, and defending data-based conclusions. Accomplishing this task in just 10-weeks, without the pressure of publication is an ambitious task requiring carefully constrained research topics and careful scaffolding. Accomplishing this task and producing publishable results is nearly impossible. It does occur, but all data indicate that it was rare.

Conclusion 2: The results of this study have implications for retention issues. The data indicate that the REU experience had little or no impact on the participants' intention or desire to retain in the STEM fields, regardless of the quality of the participants' experiences.

Although this is a study related to the educational function of the REU as described by participants, there are implications for the impact of the REU on retention. One of the implicit goals of the REU program is that it teaches women about the pathways into graduate school and the nature of graduate school, and provides the spark needed to bolster their interest in STEM. However, survey and interview evidence strongly suggest that most students entering the REU program are already committed to a STEM career pathway. Interviews demonstrated that these women have had plenty of experiences prior to their REU that provided them with significant experiences that educated them about the nature of academic research, often going back many years. Moreover, there is scant evidence to support the notion that most students who participate in REU program are unaware of the nature of the scientific process, even as related to research astronomy. Only those very few students from the smallest of schools seem to gain some knowledge of how science is done. However, these students are rarely able to successfully compete for REU positions against a long list of more qualified applicants, who already have research experience. Therefore, the applicants who would most likely benefit from the REU experience are least likely to be accepted in to the program, diluting the impact of the program. Further , the observation that the participating undergraduates went on to STEM careers whether or not they had overly positive or overly negative REU experiences, provides necessary, if not sufficient, evidence of the REU's role as irrelevant to STEM retention.

One might suggest that the REU is an important means of educating women who are interested in STEM about the process of entering and successfully completing graduate school. An alternative, plausible assertion is that if an undergraduate has the wherewithal and determination to successfully apply for and earn one of the few coveted spots among a highly competitive list of other applicants, they probably have the knowledge and skills to successfully navigate the pathways to graduate school—an arguably easier application process. By virtue of their experiences and the amount of mentoring they have already received, it is likely that the typical REU participant is not the kind of student who needs graduate school application assistance, or additional motivational experiences to persuade them to make the attempt. REU students typically submit idealized and carefully worded letters of applications to earn a competitively selected spot in REUs. They have the savvy and talent to align themselves with teachers, scientists and faculty members from fairly young ages.

Most students already know the application package they need to present for successful entrance into graduate school. According to the urban mythology of graduate school acceptance, one of those "boxes that need to be checked" is an REU experience at a location different than their home undergraduate institution. In other words, undergraduates intent on going to graduate school need to get their REU "ticket punched." A cursory survey of all US students accepted in the last three years into graduate school at the largest astronomy graduate program in the country, at a southwestern, doctoral granting, research extensive university, revealed that 100% had REU or REU-like research experiences. This seems to confirm the folklore, whether by coincidence or by self-fulfilling prophecy, that “all” students pursuing graduate studies “should” have an REU on their resume in order to be competitive.

In some reports, such as the SRI survey, the correlation between having an REU and attending graduate work, is viewed as a cause and effect relationship. They assert that “[undergraduate research opportunities] increase the likelihood of obtaining a PhD,” while seeming to forget that correlation does not imply causation. These studies neglect to validate results by searching for and eliminating possible omitted variables, and they assume directionality in the possible causal relationship. They neglect to investigate the other conditions that simultaneously support REU participation and PhD studies: encouragement and recommendation from home institution faculty, prior experience, lifelong interest in STEM, and the support of family and a larger social network. Further, the claims made in these studies give no attention to the obvious possibility that a strong interest in obtaining a PhD increases the likelihood that one will participate in an REU.

If one decided to engage in the idea that there is a cause and effect relationship is at work, the principles of relative dating should be taken into account. It is reasonable to assume that women do not randomly participate in REU programs, but apply to programs that make the effort of application worth their while. As evidence of their intentions we can also assume that REU program directors only extend invitations to their competitive programs to women with substantial evidence of serious interest in the field. Serious interest in the field had to have predated the REU. The notion that the REU created the interest that must have existed before the REU could occur, defies logic. Moreover, no participant in this study indicated that the REU sparked their interest in astronomy research, or produced an interest in astronomy graduate studies. The data from the 51 women who participated in this study provide no evidence that the REU had any impact on retention in astronomy or the broader STEM fields. It is more likely that the REU programs choose, rather than served to create, women who are destined to be successful in STEM.

Conclusion 3: The participants in this study shared accounts of experiences and relationships in their development that they described in terms of meaningful educational experiences. These accounts were always attached to extended relationships and authentic scientific experiences, in stark contrast to the typical REU. All of these experiences occurred long before the REU.

This suggests that the REU is too little, too late.

This study indicates that REUs failed to provide these women in astronomy REUs with important educational experiences or mentoring. It also reveals that these women were gifted with other extraordinary experiences that provided them with knowledge, skills, determination and a robust self-concept. In each instance, key experiences shared four characteristics. First, these experiences were always extended in nature, lasting months, and in several instances, years. While the formal portion of some of these experiences only lasted several weeks, even the shortest engagement was extended through follow-up experiences or extended social networking.

Secondly, each experience involved science content or research topics that stemmed from the participant's natural curiosity, or that grew organically from work the participant was already pursuing. In their work related to science education, Carlone and Johnson discuss the need to engage learners in problems that not only involve ambiguity, but also demand students to bring their knowledge to the task (2007). In contrast, astronomy REUs involve the kind of work in which students "follow recipes, perform routine procedures, [and] rehearse technical skills." (Gough 1992, p.6). REU participants in this study reported that their rich sources of creativity and prior astronomy knowledge were not needed, at all. This type of work is typical of the most mediocre of high school and college laboratories (Gough 1992). Participants in the well-funded REU program described their work as following prescribed coding procedures, cleaning "other people's dirty data," and pressing "integrate."

As opposed to an astronomy REU that parachuted the participant into someone else's research world, the many important research and educational experiences reported by women in this study, involved an evolution of research ideas. Many researchers suggest that women tend to thrive on experiences that allow them to be contextual in their thinking. As McClintock said, there is a need to "get a feel for the organism" (Fox-Keller 1983). While there is a spectrum of behavior in any group of individuals, women tend to shine when reasoning about content that is close to them personally (Sjoberg and Imsen 1988). Therefore, abruptly entering into an existing project, with little background knowledge and little time to be assimilated to the workgroup, (i.e.: the existing REU structure) is a poor model for tapping into a woman's highly developed, situational ways of thinking.

In their younger years, participants' educational experiences often consisted of activities designed to spark interest or build excitement. From middle school and into the undergraduate years, important experiences allowed participants to construct meaningful research projects. This was true in instances where the participant was a lone junior member working with a more senior member of the astronomy community, or when they were engaged the research process with a peer group. At times, the participant designed the research projects, and on other occasions, the topic was provided to them. In all cases deemed to be of high educational value, by the participants themselves, they were involved with the entire project, from start to finish.

More importantly, these important educational experiences involved inclusion in a community of practice. When describing the scenarios that had the greatest power to explain their education in astronomy and their development as a scientist, all participants emphasized the value of the people with whom they shared the experience. The literature has established that females learn well through collaboration, in groups, and wherever the discussion of ideas is central to the tasks at hand (Collings & Smithers 1984). The solo nature of much of the astronomy REU is not a good match for the existing theoretical model.

All interview participants provided accounts of family members, teachers, scientists, professors and others who mentored them in their astronomy interests.

Learning science, becoming scientifically literate, involves learning to talk and argue in the language of science (Lemke, 1990). The social activity of learning science involves the cultural transmission of scientific practices among people within a particular social group (Kelly & Green, 1998; Toulmin, 1972). It is clear: the people with whom they shared a key activity, as much or more so than the activity itself, influenced participants' thinking about the value of astronomy as a field of practice. These individuals shaped how these women viewed themselves and their potential.

Finally, each of the experiences that participants describe as educationally valuable occurred when they were young. Most participants stated that the most pivotal experience in their education occurred prior to or in high school. The latest event occurred in the sophomore year of college. In each case, these experiences rested upon years of activities that built upon interests, and provided the opportunity to develop process and critical thinking skills. Together, the data provided by the participants in this study point to transmitted and modeled values for scholarship, extended scientific experiences going back to middle school, and professors who took extra time to build long-standing relationships. This study indicates that the role of family, friends and early mentors in the education of women is crucial, far outweighing the ephemeral influence of REU mentors.

Taylor (1985) described how childhood's "acts of imitation" become superseded as we grow by actions expressive of personal intention. For most of these women, the childish imitative acts of science and astronomy, in the elementary years, were necessary parts of becoming astronomers. Later supporting activities replaced the imitative acts by acts of volition, into the physical sciences. For these women, this had largely occurred by the time they were in high school. This was true, sometimes in spite of, and occasionally because of, the pressure to conform to a peer group. In the case of these women, those middle school and high school activities provided reinforcement for scientific activity, while creating peer groups that were equally involved in developing science identities. The data clearly suggest that the interaction of very early imitative acts, with adolescent volitional activity, provided for rich and intense educational outcomes. These are the forces by which enculturation into the complex scientific and astronomy communities occur.

Pragmatic Implications

This section briefly discusses the political and social structures that might be informed by the conclusions of this study. This is followed by recommendations based on the study's conclusions.

Facing the Status Quo Bias

"The status quo is the only solution that cannot be vetoed. " (Kerr 2001, p. 134).

There are significant barriers to changes to, or elimination of the REU program. Stakeholders find the REU programs sentimentally tasteful. These stakeholders include faculty mentors, program directors who donate their time to win and administer the REU awards, and program officers who can point to a specific example of supporting the STEM career pipeline. Given that backdrop, the results of this study can certainly be classified as "disappointing" for many scientists, and in fact, dissemination of this study's early results has often been met with a degree of disbelief, if not outright hostility. Many well meaning scientists have believed that by contributing time and effort to mentor students, during what is a scientist's highly productive summer research time, they would be making a difference in these participants lives. Data suggesting that their efforts related to the REU program have been for naught, represent a discrepancy between their existing self-concepts and reality. (Higgins, 1987). As a result, these findings will, no doubt, be met by dismay from stakeholders.

Hosting an REU also has career and political benefits for faculty and institutions, just as it does for students. Most REU-type programs are funded by an extramural grant or contract award, which counts as scholarship for faculty promotion and tenure reviews. Such an award also can count positively in the expectations for faculty to engage in research, teaching, and service. Perhaps more importantly, departments and colleges are able to point to active participation in supporting the STEM career pipeline which is politically popular and emotionally satisfying. And, it cannot be ignored that extramural funding also comes with a financial reward for the institution in the form of indirect overhead or, in the specific case of NSF-sponsored REU's, a 25% administrative allowance. Moreover, given that federal agencies, including NSF, NIH, NASA, and NOAA, have allocated nearly 1 billion dollars to this program over the past two decades, the bureaucratic inertia related to the program may be nearly impossible to overcome. Taken together, these realities represent a great disincentive for program providers to actively question the true impact of REU program. It seems likely that the NSF-sponsored REU program will continue, almost unchanged since its introduction to universities in 1987, regardless of the findings from this or any other study.

Alterations and Alternatives to the REU program

Findings from this study have implications for other pathways that we might take as we attempt to educate and enculturate women like those who participated in this study, into science. Based on the experiences of the women in this study, there may be ways in which the REU program can be modified to increase its impact, while other types of interventions may prove to be even wiser investments of funds and stakeholders efforts.

Altering the REU program

If the REU is to fulfill its stated goal of being a valuable and durable educational or transformational experience for women in astronomy, it will need to assimilate some of the characteristics of experiences that the women themselves describe as meaningful and important. The four common characteristics are: extended engagement, personally meaningful investigation, immersion in a community of practice, and early engagement. It is possible to envision how these might be incorporated into the REU program, based upon existing models described by participants. These characteristics are intertwined; improving one will improve the other. The ways in which this could be done are numerous, allowing for many possible solutions, tailored to the needs and personality of each institution.

Extending the experience and increasing community within the existing structure.

One potential alternation of the existing REU program is framed by the concept of building a community of enculturation into the practices and mores of astronomy.. The figure at the center of this community is the mentor, the essential player in the enculturation process. However, Brickhouse and her colleagues (2000) suggest that research scientists, as an undifferentiated group, are not necessarily the best persons to enculturate women into science, or specific to this case, astronomy. One reason for this is that research scientists are often “distant and irrelevant” to the participants. In the survey and interview data, participants frequently described their REU mentors in those terms. This is a stark contrast to the informal mentors encountered in middle and high school, and to many home institution mentors. The second reason that the astronomy REU mentor may not be an effective vehicle for enculturation is that they represent "an excessively narrow view of what it means to engage in science." They frequently gave their participants extraordinarily narrow data sets, associated with a highly specialized sub-topic in their field, and little means of situating that research into the larger scope of astronomy. Little attempt is made to teach broad research skills, or to discuss the philosophical approach employed in the research.

At this time, most REU participants work on their projects by themselves, with mentor interaction that ranges from occasional assistance and intellectual discussion, to no interaction at all. This should not be surprising as the participant and mentor are strangers. The mentor is at their own home institution where the terrain is likely so familiar that it has become invisible, and is typically operating under pressure to complete research during the summer months. Meanwhile the undergraduate is in foreign territory, where the stresses of mundane tasks, such as getting to a grocery store, are overwhelming. At the same time, they are at different career stages, with differing sets of content and research knowledge. It is far-fetched to believe that they can form the kind of community relationships that these women described as being highly influential, in 10-weeks and under those conditions.

If the program is to stay in its present format, with single students traveling to foreign institutions, there are at least two ways in which a community of practice can be encouraged. First, the practice of solo projects can be altered, so that students always work on a project with a mentor and two or more other undergraduates, in addition to graduate students who may engage in the group. While they will still be strangers to each other, the undergraduates will at least have the opportunity to work with one other person like themselves. Three or more undergraduates working together on the project team would provide a collaborative learning group, in which many of the current frustrations (e.g.: learning to code, debugging, lack of intellectual discussion regarding astronomy) would be shared and perhaps eliminated. This would provide the sense of: “Hey, these people are like me,” that participants said they valued in other programs, such as the Summer Science Program (in Ojai, California and Socorro, New Mexico). The sense of isolation that many participants describe in the current REU structure would be reduced. Moreover, with three students working on a project, the likelihood that projects might be completed by the end of summer would be increased.

A second way to increase a sense of community would be through continued online interaction, with interactions beginning prior to the 10-week REU and continuing on through the academic year. At this time, there are some mentors who do initiate contact with the participants prior to their arrival on-site. However, this usually consists of emailed introductions and journal articles. While the introductions show an attempt at good manners, if nothing else, they do not seem to start the formation of a relationship. The emailed journal articles, as described in Chapter 4, are frequently highly specialized, and decontexualized from the participant’s point of view. As evidenced by the number of participants who privately state that they didn’t understand the readings, and the number who at the end of the summer, still cannot describe the purpose of their projects, this well-meaning attempt at an early start, is not working.

Instead, one might propose more meaningful interaction. The journal articles could still be included, but now with introductory readings that will provide context and content background. In addition, in an age of blogs, virtual labs, webcams, webinars, and Skype, participants can and should be attending research group meetings from the time that they are selected for a project, until the project is completed. Even if they simply sit and listen, they will come to know the names, faces, and voices of those with whom they will be collaborating. No doubt they will acquire the language used by the project team, and begin to ascertain the important issues. If there is no research group, but a single investigator, that investigator can begin to have regular, perhaps weekly, short meetings, where participants can begin to acquaint themselves with the research materials and the person who is to be their mentor.

Altering the Structure of the REU to support the program's educational function.

Two simple changes to the REU program would both serve to extend and nurture the research community. First, participants should be encouraged to return to the same REU site for a second year. At this time, there is an untested assumption that attending a variety of sites is a benefit in the current program. However, there is no evidence from this, or any other study of REUs, to support that hypothesis. To the contrary, there is evidence that the REUs are indistinguishable in their impact, and as described in the conclusions to this study, the short time frame spent at one institution is a barrier to learning. Any concern that this will reduce the number of women who attend REUs can be countered with the data on women who already take two or three REU slots, at different institutions. The number of slots they consume will not change but by encouraging participants to return, many issues will be resolved (e.g.: there is not enough time to get to know the mentor, not enough time to come to know or complete the project, stresses related to living in an unfamiliar environment, etc.).

Return to the site would be voluntary, with both the participant and the mentor knowing that good performance will result in a return invitation and acceptance. It is reasonable, albeit untested assumption, that this structure may encourage all parties to invest more of themselves in the work. Negotiating a mutually beneficial research relationship may become a priority, and providing additional research and content-knowledge support to an undergraduate may become an investment with a larger pay-off. An undergraduate who returns would know the content and context of the project. They would be familiar with the software required, and would need less support in terms of familiarizing themselves with equipment. They would be exponentially more productive. Moreover, there is a good likelihood that they will have invested their own time and energy into the project during the interim academic year; a two-summer REU research assistant might naturally evolve into a 15-month research assistant. In return, the participants might find that they are no longer marginalized into throw-away projects where they are asked to make sense of the mentor's "dirty data." They would now be engaged in a long-term project, where their contribution would be meaningful, and where they would be part of a research team. They would likely attempt to impress, and they would be looking for programs where they know mentors engage students for multiple years. One can imagine that institutions would no longer tout the number of women in their REU program, but the number of women who valued their program enough to return for a second year.

Another alternative involves engaging the faculty from the home institution, in two different ways. First, institutions with REU programs could simply be encouraged to engage their own students in their summer program. Using the same types of academic year extensions suggested in the previous section, this would mitigate all concerns about acclimating to new surroundings, becoming familiar with the mentor, the need for extended research experiences, and the need to become part of the community. While there are some who might suggest that attending an REU at a foreign institution is a crucial educational experience, there were no data to support that assertion. Instead, as described above, it provokes many problems. Another exception to this suggestion is the folk wisdom notion that REUs serve as a recruiting mechanism. However, the program is not intended for that purpose, and there were no reported data to support the idea that the program functions in this way. Instead, it should be noted that of the 51 women who participated in this study, none of them attended their various REU sites for graduate school.

An intriguing variation on this is to include the home institution faculty in the program at the REU institution. REU institutions could send out applications, not just to solo undergraduates, but to undergraduate teams, consisting of a faculty member and two or three undergraduates. One can imagine the REU institution sending out a solicitation for teams that would be interested in working on a portion of a larger research project, in a sense disaggregating the project and farming out a small portion to a cooperating team. This would be particularly attractive to faculty from liberal arts or small institutions who do not have access to the kinds of expertise and equipment available at many of the REU sites. As the REU experience is most likely to benefit undergraduates from these kinds of institutions this is a good match. Further, the home institution faculty may bring a missing skill set to the REU program. Just as many productive researchers have subordinated their teaching and mentoring in order to increase their research skills, many of the home institution faculty have subordinated their research interests to their interest and talent in working with undergraduates. The two faculty groups bring complimentary skill sets that could combine to provide significant educational benefits to the REU participants. Value added benefits are many, such as the chance for the home institute faculty to collaborate and publish with REU faculty on projects while jointly mentoring undergraduates. A partnership between REU and home institution faculty provides the structure to extend research experiences and offer a community of practice, and to do so more richly, than any of the other suggestions on their own.

Alternatives to the REU program

While these suggestions for alterations to REUs are likely to greatly improve the educational quality of the program in astronomy, they fail to address two of the characteristics of important educational experiences for women in astronomy. These two features: engagement derived from participants' particular interests, and early engagement, suggest that other types of programs may be useful in accomplishing the goals of educating women and drawing them into the STEM pipeline. As in the previous section, these two characteristics are intertwined, and an intervention to address one will likely address the other. Interventions intended to focus on participants' scientific and research interests can easily be enacted in a few age bands: the primary years, middle school through high school, and the early undergraduate years. As demonstrated by participants' descriptions, many programs that meet these criteria, already exist.

Programs for primary children.

In the primary years, participants' experiences involved family members and the generation of excitement. Existing programs of this type include 4H, scouts, and astronomy specific programs such as Family Astro. Family Astro is a program coordinated by the Astronomical Society of the Pacific with partial funding from NSF. Developed to help families, youth groups, after-school clubs, and other groups to engage in "the exciting ideas that underpin our understanding of the universe." The intent of the program is "to help parents (and other caregivers) to get more involved in their children's science education, and to spend more time together in active experiments, observations, and discussion." (Astronomical Society of the Pacific 2009). Family Astro activities are frequently held in planetaria and museums, and mirror the types of activities the women described in the interview portion of this study. The same important people are involved: family member and after-school group leaders. By the nature of those relationships, these experiences are tied to positive emotions, a sense of belonging, and a reaffirmation of potential. Moreover, because parents, teachers, and other caregivers are the leaders of the activities, these are naturally extended experiences.

At the present time the majority of young children who engage in these programs are those who have attentive and education-oriented parents. Modifications of these programs to activate other caregivers could provide equal opportunities to additional children and serve to increase the number of children who enter the STEM pipeline. Funding of these types of programs is one means to insure an adequate flow of STEM professionals, regardless of the number of subsequent leaks in the system.

Middle school, high school and the undergraduate years.

In the middle school and high school years, study participant's reported that important experiences occurred through school, and in a few specific types of summer programs. Two types of programs were mentioned related to schools: those that engage a teacher and a student in research together, and coursework that was provided using reformed instruction. In the previous section, a suggestion was made that home institution faculty should accompany undergraduates in their REU; participants described similar programs in the 6^{th}-12^{th} grade years as high quality educational experiences. In these programs a teacher selects one of more students to collaborate with them on a local research project. These programs highlight the extended relationship between the mentoring teacher and the student, and research that is locally significant.

Within schools, reformed instruction in science courses attracted some participants for their focus on problem solving and the social construction of knowledge. It is important to note that the important factors in these courses were related to students doing science and doing it collaboratively, where their interests, knowledge and skills were useful. In contrast, there are many programs currently enacted in classrooms that relate to guest scientists in the classroom, or teachers engaging in summer research and bringing that back into their classrooms. In no instance did a participant mention such programs, nor is there any reason why they should have. Those programs do not focus on the engagements of students and as such, they are not learner centered. This suggests that funding might be better spent on teacher pedagogical training, rather than on programs involving "real scientists" (Slater, Slater & Olsen 2009).

Educationally effective high school summer programs share many of the same characteristics as effective undergraduate programs. They extend over a long period of time, they engage students in the full scope of the scientific process, are often centered on the students' research interest, and they involve enculturation into a community. Some programs, like the Summer Science Program engaged students in directed research projects; all students complete work in celestial mechanics, specifically the orbit of comets. The program is highly structured, including instruction in advanced academic courses and programming. While the research questions are fairly predetermined, all students participate in the "entire research project from start to finish ... observations, measurements, and calculations. … At the end of six weeks, each [student has logged] many hours of experience with the collection, measurement, analysis, interpretation, and presentation of scientific data. Each team's observations [are] submitted to the Minor Planet Center at the Harvard-Smithsonian Center for Astrophysics…." (Summer Science Program 2009.) The research process and the research problem are authentic. Another highly effective program is the Research Science Institute (RSI) program held at the Massachusetts Institute of Technology (MIT). At RSI "participants experience the entire research cycle from start to finish. They read the most current literature in their field, draft and execute a detailed research plan, and deliver conference-style oral and written reports on their findings. ... Projects are open-ended and relevant." (Center for Excellence in Education 2009) Other highly valuable summer programs for high school students include the NSF's Young Scholars Program and Summer Science Camps program, both now dismantled. These programs were specifically mentioned as important experiences by the women in these studies, suggesting that these two programs, or programs like them, are worthy of consideration in future program decisions.

Each of the four programs mentioned here functioned to allow high school students to explore science in a collaborative setting, in a community of science practice and language. Participants reported that these programs provided them with a sense of belonging that has remained many years later. Indeed, these programs deliberately create a sense of community among participants, long after they have exited the program, through the creation of virtual alumni communities and yearly alumni reunions.

In the undergraduate years, the Undergraduate Research Opportunity Program (UROP) is held during the academic year and features many of the same characteristics as the effective high school programs, with even more opportunity for extended mentoring relationships, and more opportunity for students to engage in projects that match their interests. According to the program description at MIT, the UROP "offers the chance to work on cutting edge research—whether [the student joins] established research projects or [pursues their] own ideas. As UROPers, undergraduates participate in each phase of standard research activity: developing research plans, writing proposals, conducting research, analyzing data and presenting research results in oral and written form. UROP projects take place during the academic year, as well as over the summer, and research can be done in any academic department or interdisciplinary laboratory." (Massachusetts Institute of Technology 2009) The University of Michigan UROP program further engages students in bi-weekly research seminars, and assigns each UROPer a peer advisor. (University of Michigan 2009).

The only disadvantage to these programs, is that they are targeted at the most talented students who already have accrued many hours of scientific experiences, especially the SSP and RSI programs. The RSI program, for instance, only admits "80 of the world's most accomplished high school students" (Center for Excellence in Education 2009). These programs are pedagogically sound, and by alumni accounts, highly effectively, but they are only available to a small number of the most talented students. New programs based on these models, modified to serve a larger number of high school and undergraduate students are needed to retain and educate additional students. The excellent programs that we provide to our best and brightest, can and should be extended to others.

Future Studies

This study focused on the educational experience of women who participated as undergraduate researchers in astronomy REU programs. One might also be initially tempted to see this as gender study of "women in science." In the end, this really is a study about people in science, more than a study of women in particular. In absence to any evidence to the contrary, it seems reasonable to assume that the results might be similar for male participants. A cursory review of annual evaluation reports related to this study, supports this assertion. In terms of looking toward future questions to pursue, we suspect that the experiences of the men who participant in these programs, is similar. As Brickhouse (2000) suggests, many of the perceived differences between males and females in the sciences, no longer apply. However, differences in experiences that men and women describe as important are as yet undetermined. Additional insight would be useful to individuals studying this phenomenon.

It should be noted that the participants in this study largely shared two characteristics that may be of importance: they were all sufficiently gifted to successfully apply to a highly competitive program, and they were applying to a field that was very familiar to them. It is unclear that these same results would be found if this study were to be repeated with a group of women from a less selective REU program. Given the importance of prior experience in diminishing the impact of the REU for these highly accomplished young women, it is reasonable to wonder if the REU program might have a much greater impact in the lives of women who lack such prior experiences. An inspection of the literature indicates that no study has looked at the differences in the experiences of women in top-tier and second-tier REU programs. In addition, as indicated by this study, it would be difficult to argue that these women were drawn to astronomy by their REU experiences, as the participants reported early interest in the field, and nearly all of the participants were completing undergraduate majors in astronomy, or physics where astronomy was not available. However, there are some fields, such as oceanography, that rarely exist in the undergraduate curriculum as a major, giving students little opportunity to explore those areas as potential fields for graduate studies or careers. In those fields REUs may serve an important recruiting function, indicating that this may be an area of further research into REUs.

Perhaps more interesting would be to expend effort studying the scientist mentors themselves. The original evaluation reports cited mentors as often being reticent to participate in evaluation studies. As most mentors were men, and men are often seen as being less spontaneously reflective than women, extra and purposeful effort is likely needed to uncover how senior scientists envision and enact the mentoring process from their own perspective.

Finally, the question of impact on the STEM pipeline, if the REU program simply disappeared, is worthy of investigation. Potentially, this could be pursued by finding graduate students and early career scientists who did not participate in REU programs and comparing them to those individuals who did. However, it seems that the population of such individuals is likely quite small and the confounding variables would be difficult to separate.

While certain to be controversial, the survey and interview evidence reported in this study, was collected from large portion of the women educated in astronomy, over eight years, across multiple REU sites. These data are judged to provide clear evidence that experiences like the summer REU are largely irrelevant in the education of women in astronomy. Further identification and understanding of other more effective educational experiences might be a fruitful line of future inquiry.

APPENDIX A- INITIAL EMAIL SOLICITATION

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SURVEY SENT TO PREVIOUS REU STUDENTS

*** * *** * *** * *** *** * *** * *** * *** *** * *** * *** * ***

Hi. I hope you remember me, my name is [*edited*] We met when you were involved with the REU program at [*edited*]. I need to do just an important bit of follow up and was curious if you could send me a TWO or THREE sentence email that I can add to my annual alumni follow-up report describing what previous students are up to. This should not take more than a minute or two and it would be enormously helpful if you could quickly do it RIGHT NOW.

1. What are you doing this summer and where (is this different than what you were doing before)?

2. What are your school or work plans for this upcoming fall and where will you be (if you are conducting research, on what topic (does your study have a title yet?)?

3. If you are in school, what school are you going to, what year are you, when do you think you might graduate and what will your degree/thesis be (do you have a title yet? What is it?)?

4. What is the best long-term email address to use to find you?

AND

5. One more thing, we are beginning a longer survey in an attempt to explore the nature of educational experiences in the lives beginning scientists. We are asking people to volunteer to participate in a confidential telephone interview which will last about 45 minutes.

This survey is voluntary, completely confidential and your results will be completely separated from any identifying information, so your name will not be attached to your responses in any way. There are neither known risks nor direct benefit of compensation for your participation.

If you would be willing to help us out and participate in a telephone interview, please send a private email to [*edited*] within the next week or so and she will send you more information and schedule a time to call you at your convenience. Thank you so very much for your consideration in helping us out.

And, as always, thank a million! You make my job so much easier!!! I hope to see you at an upcoming meeting and to hear from you soon!! If you could reply privately to me at [*edited*], that would be awesome. Cheers, [*edited*]

*** * *** * *** * *** *** * *** * *** * *** *** * *** * *** * ***

APPENDIX B- FOLLOW-UP EMAIL SOLICITATION

Hi [*Participant*],

I'm Stephanie Slater. I don't know if you remember me, but I was part of the original team of researchers that worked on the evaluation of the REU at [*edited*]. I was forwarded a copy of the email that you sent to [*edited*], stating that you would be willing to be interviewed for a study related to the educational experiences of scientists.

I'd like to tell you a little more about the study, before asking you to commit to participate. This study intends to explore the kinds of educational experiences that women in astronomy have had. We think that the best way to get at that kind of information is through interviewing women who have engaged in astronomy.

You should know that there is no right or wrong answers in the interview. We don't even know what the right answer is! We really don't know a lot about these issues, so what we're doing is something called "grounded theory". That basically means that we're building our knowledge in this area from the ground up! Also, this research perspective really honors the meaning that the actors (that's you) make of events. The way in which you make meaning of events in your life is actually more important for understanding these kinds of things, than the actual events themselves. Most hard scientist find sociological research to be kind of wierd....so don't think about it too much. We'd just like to know how you see things.

If you are interested in participating, please read the attached disclosure statement. It basically says that the information you provide will be completely confidential, you can stop participating in the study, and there are no known risks, or any promised benefits from the study.

If you are still interested in participating after reading the disclosure, I would be conducting the interview and would like to do that as soon as you might be available. I promise that I won't hold you longer in the interview than 45 minutes. I know that this is a busy time of year, and I respect you time.

You can indicate that you would like to participate by replying to this email, with a couple of times that would work for you in the next two weeks. I'll email back to confirm, and thanks for being willing to assist us in this research.

Cheers,
Stephanie Slater

Attached Disclosure Statement

Introduction

You are being invited to take part in a research study. The information in this form is provided to help you decide whether or not to take part. Study personnel will be available to answer your questions and provide additional information. By responding to this email, scheduling a time for a telephone interview, and completing the interview, you are indicating your consent to participate.

What is the purpose of this research study?

The purpose of this study is to deepen our understanding of what experiences you have had that impact your education as a woman in the sciences

Why are you being asked to participate?

You are being invited because you have previously been enrolled in an undergraduate degree program in a science discipline.

How many people will be asked to participate in this study?

Approximately 10 persons will be asked to participate in this study.

What will happen during this study?

You will be asked to voluntarily participate in a 45-minute, confidential, telephone interview.

How long will I be in this study?

About 45 minutes of time in total will be needed to complete this study.

Are there any risks to me?

Participation in the telephone interview has no known risks of any kind. Although we have tried to avoid risks, you may feel that some questions we ask will be stressful or upsetting. If this occurs you can stop participating immediately. We can give you information about individuals who may be able to help you with these problems.

Are there any benefits to me?

You will not receive any benefit from taking part in this study. However, it is hoped that this study will our understanding of what impacts individuals' career choices.

Will there be any costs to me?

Aside from your time, there are no known costs for taking part in the study.

Will I be paid to participate in the study?

You will not be paid for your participation.

Will video or audio recordings be made of me during the study?

We will make an audio recording during the study so that we can be certain that your responses are recorded accurately. By responding to this email, scheduling a time for a telephone interview, and completing the interview, you are indicating your consent to participate and give your permission for audio recordings to be made of you during my participation in this research study. These recordings will be converted into a typed document by the PI and all identifying information will be removed. Afterward, the recording will be destroyed and no one other than the PI will hear the recording.

Will the information that is obtained from me be kept confidential?

The only person who will know that you participated in this study will be the researcher, Stephanie J. Slater. Your records will be confidential. You will not be identified in any reports or publications resulting from the study. It is possible that representatives of the sponsor that supports the research study will want to come to The University of Arizona to review your information. Representatives of regulatory agencies (including The University of Arizona Human Subjects Protection Program) may access your records. If that occurs, a copy of the information may be provided to them but your name will be removed before the information is released.

What if I am harmed by the study procedures?

We do not anticipate that you could be harmed in any way by the study procedures. Although we have tried to avoid risks, you may feel that some questions we ask will be stressful or upsetting. If this occurs you can stop participating immediately. We can give you information about individuals who may be able to help you with these problems.

May I change my mind about participating?

Your participation in this study is voluntary. You may decide to not begin or to stop the study at any time. Your refusing to participate will have no negative impacts on you.

Whom can I contact for additional information?

You can obtain further information about the research or voice concerns or complaints about the research by calling the Principal Investigator Stephanie J. Slater and can be reached at (520) 975-3826. If you have questions concerning your rights as a research participant, have general questions, concerns or complaints or would like to give input about the research and can't reach the research team, or want to talk to someone other than the research team, you may call the University of Arizona Human Subjects Protection Program office at (520) 626-6721. (If out of state use the toll-free number 1-866-278-1455.) If you would like to contact the Human Subjects Protection Program via the web, please visit the following website: http://www.irb.arizona.edu/contact/.

Your Consent

By responding to this email, scheduling a time for a telephone interview, and completing the interview, you are indicating you have read the information contained in the form, that the study has been explained to you, that your questions have been answered and that you agree to take part in this study. You do not give up any of my legal rights by participating in an interview.

APPENDIX C- EXAMPLE OF SUMMER SURVEYS

Sample 1: Likert-type survey

Aspect of Science	Strongly Agree				Strongly Disagree
I allocate significant time reading scientific journal articles	5	4	3	2	1
I formulate my own hypotheses to be tested	5	4	3	2	1
I test hypotheses given to me by other people	5	4	3	2	1
I allocated significant time to writing computer code for data processing	5	4	3	2	1
I spent time trying to figure out how to work in UNIX	5	4	3	2	1
I spent time trying to learn how to use IDL, IRAF, etc	5	4	3	2	1
I must propose to my faculty mentor which questions I want to pursue	5	4	3	2	1
I designed my own summer research project	5	4	3	2	1
My data comes from telescope observations which I participated in	5	4	3	2	1
I am almost always able to tell when my computer code is not working properly	5	4	3	2	1
I deal mostly with observational data	5	4	3	2	1
I deal mostly with theoretical or contrived data	5	4	3	2	1
I extensively use my own creativity in conducting my summer project	5	4	3	2	1
I have been/will be working on a research publication or poster describing my project	5	4	3	2	1
I will/did attend and present my results at a meeting of the AAS	5	4	3	2	1
I am giving/gave a research presentation on my summer work at my home institution	5	4	3	2	1
I believe that my daily activities this summer closely mimic what life as a graduate student is like	5	4	3	2	1

Sample 2: Open-ended survey

Beginning of Summer questions:

1. RESEARCH QUESTION: Describe your involvement in the development of your research project's question, hypothesis, or theoretical model. For example, your involvement might have been very limited ("my mentor told me what project I would be working on and how it fit into his large grant"); moderate ("I chose between several different projects"); or significant ("I was able to help develop the questions we are investigating or the hypothesis we are testing"). Please explain your response, citing examples when possible.

2. METHODS #1: Describe your involvement in the initial design of your observational methods/experimental design/data analysis methods. For example, your involvement might have been very limited ("my mentor told me what data we would analyze to answer our questions"); moderate ("my mentor gave me the data, but I figured out how to analyze it" or "I helped figure out which data to collect or how to analyze the data, with help from my mentor"); or significant ("I decided what data and analysis was needed in order to answer the question"). Please explain your response, citing examples when possible.

Mid-Summer questions

3. METHODS #2: Describe your involvement in any major modification(s) of your observational methods/experimental design/data analysis methods. For example, your involvement might be (or have been) very limited ("I had very little input into the changes we made" or "we didn't make any major modifications"); moderate ("I helped my mentor decide on the modifications that were needed"); or significant ("I proposed the modifications to my mentor"). Please explain your response, citing examples when possible.

4. DATA COLLECTION: Describe your involvement in the collection of the data you are using in your project. This might include the original data YOU are analyzing (or have analyzed), or additional data for the same project that will be analyzed later. For example, your involvement might have been very limited ("my mentor gave me the data she/he had already collected"); moderate ("I helped figure out which data to collect/find, with help from my mentor"); or significant ("I decided how to collect/find my data"). Please explain your response, citing examples when possible.

5. DATA ANALYSIS: Describe your involvement in the analysis of the data you are using in your project. For example, your involvement might be (or have been) very limited ("I followed the step-by-step directions that were given to me to analyze the data or theoretical model"); moderate ("with the help of my mentor, I developed a strategy for the analysis of the data or theoretical model"); or significant ("I used considerable logic and/or creative insight of my own in the analysis of data or theoretical model"). Please explain your response, citing examples when possible.

End of Summer questions

6. FUTURE RESEARCH INTERESTS: What are your plans in regards to graduate school and astronomy?

a. If you plan to go to graduate school in astronomy, is the topic you researched this summer one you would like to continue working on as a graduate student? If you do not plan to continue on this research topic, what do you hope to study?
b. If you do NOT plan to go to graduate school in astronomy, what are your plans?
c. In either case, how has THIS SUMMER'S REU EXPERIENCE influenced these plans?

7. EXPLANATIONS/CONCLUSIONS: Describe your involvement in the interpretation and/or explanation of the results of your project. For example, your involvement might be (or have been) very limited ("my mentor told me what the results suggest about our question or hypothesis"); moderate ("I had some ideas about what our results suggest about our question or hypothesis, but needed help from my mentor"); or significant ("I told my mentor what the results suggest about our question or hypothesis"). Please explain your response, citing examples when possible.

8. COMMUNICATING RESULTS: Describe your involvement in the communication of your project's results. For example, your involvement might be (or have been) very limited ("my mentor will include these results as part of a larger project/paper/poster, but I'm not involved" or "we aren't doing anything else with this project"); moderate ("I am a co-author on our paper/poster, but my mentor is doing most of the writing"); or significant ("I am doing the majority of the work to prepare a paper/poster, with my mentor as a co-author"). Please explain your response, citing examples when possible.

APPENDIX D- PARTICIPANT TIME LOGS

FRIDAY AUGUST 12, 2005	Learning software (e.g., reading manuals, doing tutorials, meeting with someone)	Reading papers, journals or books	Listening to talk or seminar	Meeting with REU mentor	Meeting with postdoc/grad student on research project	Talking with other REU students about research	Email (only mark if a significant block of uninterrupted time)	Data analysis (e.g., working with IRAF or IDL, looking at spectra, calibrating images, etc.)	Programming / debugging code	Building, repairing, or testing instrument or other hardware	Observing run	Preparing poster, talk, or paper	Other REU-related (*please describe in NOTES section below*)	Activity not related to REU research (e.g., lunch, personal email, ripping CDs, sightseeing, commuting, etc.)
Prior to 8:00am														
8:00-8:30am														
8:30-9:00am														
9:00-9:30am														
9:30-10:00am														
10:00-10:30am														
10:30-11:00am														
11:00-11:30am														
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12:30-1:00pm														
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1:30-2:00pm														
2:00-2:30pm														
2:30-3:00pm														
3:00-3:30pm														
3:30-4:00pm														
4:00-4:30pm														
4:30-5:00pm														
5:00-5:30pm														
5:30-6:00pm														
6:00-8:00pm														
After 8:00pm														

APPENDIX E- EXAMPLE OF ALUMNI SURVEYS

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SURVEY SENT TO PREVIOUS REU STUDENTS

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Hi. I hope you remember me, my name is [*edited*] and I am an astronomy professor at the [*edited*]. We met when you were involved with the REU program at [*edited*]. I need to do just an important bit of follow up and was curious if you could send me a TWO or THREE sentence email that I can add to my report describing what previous students are up to. This should not take more than a minute or two and it would be enormously helpful if you could quickly do it RIGHT NOW.

1. What are you doing this summer and where?

2. What are your plans for this fall and where will you be (if you are conducting research, on what topic (does your study have a title yet?)?

3. If you are in school, what school are you going to, what year are you, when do you think you might graduate and what will your degree/thesis be (do you have a title yet? What is it?)?

4. What is the best long-term email address to use to find you?

AND

5. Now that you look back on your REU experience, could you type me a sentence or three about how, if at all, your IfA REU experience influenced what you are doing now and where your career aspirations are going?

Thanks a million! If you could reply privately to me at tslater@as.arizona.edu, that would be awesome. Cheers, [*edited*]

*** * *** * *** * *** *** * *** * *** * *** *** * *** * *** * ***

APPENDIX F- HUMAN SUBJECTS APPROVAL

THE UNIVERSITY OF ARIZONA.

Human Subjects
Protection Program

1618 E. Helen St.
P.O. Box 245137
Tucson, AZ 85724-5137
Tel: (520) 626-6721
http://www.irb.arizona.edu

HSPP Correspondence Form

Date: 05/18/09
Investigator: Stephanie Parker-Slater, PhD Candidate **Dept:** Teach/Teach Edu
Advisor: Bruce Johnson, PhD
Project No./Title: 09-0161-00 The Educational Function of an Astronomy REU Program as Described by Female Participants
Current Period of Approval: NA

IRB Committee Information	
☐ **IRB1** – IRB00000291 ☐ **IRB2** – IRB00001751 ☐ **IRB3** – IRB00003012 ☐ **IRB4** – IRB00005448 ☒ Administrative Action **FWA Number:** FWA00004218	☐ Full Committee Review ☐ Expedited Review ☐ Facilitated Review ☒ Administrative/Exempt Review – *05/18/09*

Nature of Submission	
☒ New Project ☐ Amendment ☐ Unanticipated Problem Involving Risks to Subjects or Others ☐ Response to IRB Committee ☐ Other (define):	☐ Continuing Review ☐ Protocol Deviation/Violation/Waiver ☐ Non-Compliance ☐ Not Applicable

Documents Reviewed Concurrently	**Appr: Approved** **Ack: Acknowledged** **Rev: Reviewed**
☒ Project Review Form (received 2/24/09)	Appr
☒ Consenting Instruments: Disclosure statement [version 5/18/09]	Appr
☒ VOTF	Appr
☒ Recruitment Materials: Email recruitment script	Appr
☒ Surveys/Questionnaires: Voluntary, semi-structured telephone interview questions	Appr
☒ Other (define): Previously used End-of-summer evaluation questions Site authorization letter from Timothy Slater	Ack

Committee/Chair Determination
☒ **Approved** as submitted

Additional Determination(s)

- **Exempt Approval 45 CFR 46.101(b)(2):** Research involving the use of educational tests (cognitive, diagnostic, aptitude, achievement), survey procedures, interview procedures or observation of public behavior.

Elizabeth A. Boyd

Elizabeth Boyd, Ph.D.
Assistant Vice-President, Research Compliance & Policy
Office of Responsible Conduct for Research

cc: Departmental/College Review Committee
EB:mm

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