Evaluation of the Undergraduate Research Programs of the Biological Science Initiative: Students' Intellectual, Personal and Professional Outcomes from Participation in Research.

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Executive Summary

This report is the second of two reports on undergraduate research programs funded by the Biological Science Initiatives at the University of Colorado at Boulder. This study was conducted by an independent research unit, Ethnography and Evaluation Research, also at the University of Colorado at Boulder. The first report detailed findings from the Undergraduate Research Student Self-Assessment (URSSA) survey. The report is entitled:

> Thiry, H. & Laursen, S.L. (2009). Student Outcomes from Undergraduate Research: An Evaluation of Three Academic Year and Summer Undergraduate Research Programs in the Life Sciences at the University of Colorado, Boulder, 2007-2008.

Project Overview

This evaluation study was designed and conducted at the request of the Biological Sciences Initiative (BSI) at the University of Colorado at Boulder. During the period studied, the BSI sponsored two types of programs, known as UROP and BURST, through funding from the Howard Hughes Medical Institute (HHMI). UROP (Undergraduate Research Opportunities Program) is an established university program that supports UR experiences in all fields, not just bioscience. BSI supports this program by providing individual grants for students undertaking UR in life science-related fields. UROP students in this study tended to be upper division students and more experienced researchers. The BURST (Bioscience Undergraduate Research Skills and Training) program was designed by the BSI as an introductory research experience to meet the gap in UR opportunities for less advanced students. The BSI provides a series of workshops and trainings for both programs to help students prepare for research work.

Evaluation goals and methods

We designed the current study to build upon our past evaluation work documenting student outcomes and the influence of the research experience on students' career and educational plans. We also sought to examine the quality of students' research experiences and the processes through which specific outcomes arise. The evaluation questions addressed in this report are:

1. What gains do students make from their research experiences?
2. Are students satisfied with their research experience, and with the training and support provided by their programs?
3. What critical elements of the research experience can be identified from interview responses (e.g. authenticity of experience, mentoring, etc.), and how do these contribute to student gains?
4. For each of these questions, can any differences in the UR experience and its outcomes be discerned for different student groups (if numbers permit): experienced vs. inexperienced UR participants, male vs. female participants, and white vs. minority participants?

5. What can be suggested for further refinement of the program itself, and for further evaluation studies?

We investigated these questions through the use of in-depth, ethnographic interviews with 18 BURST and 15 UROP students. In the present report, we describe student satisfaction with the research experience and the support provided by the BSI research programs. We also address students' gains from the research experience, the authenticity of their research work, and quality of advising.

Findings

Program Outcomes

<u>Support and guidance provided by program staff</u>

All BURST and UROP students were satisfied with the support they received from their program. In fact, every student comment about Lynn Wolfe and the BSI was positive, although UROP students reported less frequent interaction with program staff. On the whole, students reported that the BSI program staff, particularly Lynn Wolfe, was accessible, responsive, helpful, supportive, and organized.

<u>Satisfaction with program workshops</u>

Most students from both programs found the workshops to be helpful to their learning as well as a "good refresher" or introduction to the research experience. However, about one-half of students, particularly from the UROP program, did not recognize the value of the workshops and felt that they did not gain new knowledge and skills from the laboratory techniques training. Some students also felt that the laboratory training was not relevant to the techniques required in their research placement. These students noted that the training was specific to molecular biology research, and less applicable to animal, human subjects, or field research. Most students found the workshops focused on scientific communication—particularly the UROP proposal and poster workshops—to be very useful in introducing essential knowledge and skills for future scientists. Students also reported that both the library skills and communication skills training had helped them in their advanced coursework.

<u>Poster session</u>

Most students found the poster session to be a beneficial learning experience that offered a glimpse into the professional practice of scientists. Students reinforced and extended their knowledge through presenting their poster. However, a few students desired to engage in more scholarly dialogue and receive more expert critique of their posters and abstracts.

Research Outcomes

<u>Overall gains</u>

BSI students' gains from their research experiences were similar to those demonstrated by the students in our study of four liberal arts colleges (Hunter et al., 2007; Seymour et al., 2004). Reflecting the same proportion of gains observations demonstrated by students in the four colleges, 91% of BSI students' comments referenced gains achieved from the experience, termed "positive" observations. Thus we can conclude that much like the "best case" research experiences chronicled in the four-college study, UR at research-extensive universities offers ample opportunity for students' intellectual, personal, and professional growth.

Intellectual gains

Intellectual gains, or the category we have termed "thinking and working like a scientist," was the primary category of student gains, comprising 30% of all BURST students' and 24% of all UROP students' positive statements within the gains categories. Students described the progression of their intellectual growth and development as they became more experienced researchers. Novice students noted mastery of data collection techniques and gained critical thinking skills as they confronted setbacks and learned to trouble-shoot experiments. Though not a common outcome, some experienced researchers reported gains in higher-order scientific thinking skills, such as identifying a research question, or developing and modifying an experimental design. When students reported failure to make intellectual gains—primarily BURST students—they referenced a lack of growth in advanced analytic skills or understanding of the nature of scientific knowledge.

Professional socialization

Professional socialization, or the category termed "becoming a scientist," was the second largest category of students' comments about gains, comprising 21% of all positive comments about gains. Students described the development of temperamental characteristics, such as patience, independence, and initiative, which are necessary to become a successful researcher. BURST students often noted gains in the ability to *work* independently, while UROP students also noted growth in their ability to *think* independently about their project. UROP students also reported a greater sense of ownership over their projects. A few students did not have the opportunity to work autonomously, which kept them from developing problem-solving skills or learning from mistakes and setbacks. Students' comments highlight the ways in which undergraduate researchers develop greater independence and responsibility as they gain experience.

Gains in technical and communication skills

Technical and communication skills were also prominent gains for students, comprising 19% of all students' positive gains statements. Students reported gains in a variety of skills, including laboratory techniques and instrumentation, and scientific reading comprehension. Novice researchers described gains in laboratory, organizational and planning, and reading comprehension skills. More advanced researchers enhanced their reading comprehension skills and began to *apply* the literature to their project. UROP students reported greater gains in communication skills because their program offered more opportunities to engage in scholarly communication. The "value-added" of the BSI programs, beyond simply the research experience itself, is the programmatic emphasis on communication skills. Most students probably would not have developed scientific writing or presentation skills from their research experience alone.

Career and educational goals

Many students, including graduating seniors, were still uncertain about their future educational and career plans. BURST students more often reported interest in attending medical school or pursuing careers in health-care fields, while UROP students were more likely to cite interest in graduate school attendance and research careers.

- 50% of BURST students and 7% of UROP students had definite plans to enter a *health care career*
- UROP students were *more interested in graduate school and research careers* (40% of UROP and 11% of BURST students had definite plans to attend graduate school; while 53% of UROP students and 44% of BURST students were considering graduate school attendance)

Influence of research on students' educational and career paths
Participation in research seemed to have a modest impact on students' educational and career paths. As we found in the four-college study, research helped many BSI students to confirm prior interests or clarify competing interests (Hunter et al., 2007). Participation in research had a larger impact on UROP students than BURST students: 40% of UROP students (n=6) and 22% of BURST students (n=4) reported that they changed their career plans and are now considering graduate school because of research. On the other hand, 17% of BURST students (n=3) had been considering graduate school, yet changed their minds because of their research experience. This group of students did not change their plans due to a poor research experience; they simply discovered that the life and work of a scientific researcher was not a good fit for them.

Authenticity of students' research experiences
Nearly all BSI students reported that they participated in authentic research that could lead to publishable findings. Two students engaged only in laboratory set-up during their research experience, and a few students never advanced beyond routine data collection. Nevertheless, the majority of students reported that they made an intellectual contribution to a research project. Experienced students felt greater independence, responsibility, and dedication to their research work.

Rates of participation in academic publishing and presentation
A few BSI students—all UROP—had the opportunity to disseminate their research results to a broader scientific community. Three students co-authored a refereed paper, one student published in an undergraduate journal, and one student presented a poster at a professional conference.

Advising

On the whole, students were highly satisfied with their advisors and other interactions in the lab; indeed, 94% of students' comments about their research advisors were positive, describing the intellectual and personal benefits received from interactions with advisors and lab colleagues. Most students met regularly with their advisors; although, frequency of contact with P.I.s varied. Two students—one BURST and one UROP—reported very little contact with their advisors. Frequency of contact may be as important as quality of interaction in a UR advising relationship (Thiry et al., 2009). Findings from the URSSA survey also demonstrated that students' quantity of contact with their advisors was significantly correlated to their intellectual gains and overall satisfaction with the research experience (Thiry & Laursen, 2009).

Students identified three primary areas in which they received support from their advisors:

- ***Intellectual support*** on their research project (e.g. help with problem-solving or identifying the "next steps" of the experiment)
- ***Professional socialization*** (e.g. transmitting the values and norms of the profession, and important concepts in the discipline)
- ***Personal/emotional support*** (e.g. general comments that an advisor is supportive, accessible, friendly, takes an interest in me, etc.)

As students gained experience with research, their needs from their advisors changed. In the beginning, students needed basic knowledge and information about the project and the field, and to feel comfortable with their lab group. Experienced students needed more support in interpreting data and modifying experimental design. As advanced students became more socially and intellectually integrated into the lab, they received greater socialization benefits through their collegial, working relationships with their advisors and lab group. Everyday interactions between students and senior scientists were integral in socializing students into the profession and offering them a glimpse into the life and work of graduate students and scientists.

Conclusion and Recommendations

Almost all students were highly satisfied with both their research experience and the support provided by the BSI programs. Students' intellectual, personal, and professional outcomes from the BSI's UR programs rivaled those of the "best case" research experiences chronicled in our four-college study (Seymour et al., 2004; Hunter et al., 2007). Students also felt supported by BSI staff, particularly Lynn Wolfe, and gained insight into scholarly, professional practice through writing workshops and the poster presentation. However, a small fraction of students needed more intellectual challenge in their lab duties and guidance from senior scientists. Their experiences are instructive of the processes that result in poor research experiences, and provide guidance for mechanisms that the BSI can employ to ensure that all students are sufficiently challenged and supported in their placement.

First, while many students found the BSI workshops to be beneficial learning experiences—or at least a "good refresher" of basic knowledge and laboratory skills—some students, particularly from the UROP program, did not perceive the value or relevance of program workshops. BSI staff can emphasize the learning objectives of each workshop and how they help to develop the knowledge and skills required in scientific careers. BSI staff can also emphasize the transferability of learning from workshops to courses and non-research careers.

Since not all students engaged in bench work during their research experience, the BSI could institute optional workshops in a broader range of methods for students in varied research placements. Instead of a single mandatory laboratory workshop, the BSI could offer a series of orientation workshops based on specific research techniques, such as care of animal subjects, human subjects procedures, field research methods, preparing solutions and pipetting, etc. In consultation with their advisors, students could select the workshops most relevant to their particular placement. Thus, students' attendance would be based on the nature of their work in the lab, rather than their program affiliation. Additionally, the "value added" of the BSI programs—particularly the UROP program—is the program's emphasis on communication skills. However, the BURST program could place more emphasis on writing and presentation in a manner so that students are prepared for UROP communications activities.

Our prior research and evaluation has demonstrated the importance of engagement in authentic work with adequate guidance and support for UR students (Coates et al., 2005; Thiry et al., 2009). Almost all of the students in this study engaged in authentic research tasks and responsibilities. However, a few students—primarily BURST—engaged mostly in “busy work,” such as setting up a lab, ordering equipment, and filing invoices. To ensure that all students undertake authentic work with appropriate intellectual challenge, we recommend that advisor training emphasize appropriate project selection for novice and advanced students. Advisor training should stress that novice students be continually guided toward greater independence in both work *and* thought.

Students’ reports about their relationships with their only advisors and their lab group were overwhelmingly positive, although a few students were not satisfied with these relationships. To address the needs of these few students, we suggest that the BSI staff consider a mid-semester evaluation or check-in to assess the quality of students’ research experiences in terms of their research duties and the quality of mentoring. Some cases may merit taking action when a project is not going well. Although a poor research experience did not have major detrimental outcomes for any students in this study, our prior research has demonstrated that poor experiences can “turn off” students from the discipline and scientific careers (Thiry et al., 2009). While poor experiences are fairly rare, we do believe the best opportunity for preventing them is at the level of advisor training.

Introduction

This evaluation study was designed and conducted at the request of the Biological Sciences Initiative (BSI) at the University of Colorado at Boulder. During the period studied, the BSI sponsored two programs, known as UROP and BURST, through its funding from the Howard Hughes Medical Institute (HHMI). These programs were designed to provide research opportunities to strengthen students' science education, provide hands-on research experience, and draw students into advanced study or a career in science.

Prior evaluation of the BSI's undergraduate research programs indicated that most students were highly satisfied with their research experience and made strong gains in a variety of areas, but a minority of students may not have had access to authentic science or adequate mentoring (Coates et al., 2005). We designed the current study to build upon our past evaluation work documenting student outcomes and the influence of a research experience on students' career plans. The study was designed to gather information from students from a comprehensive survey and in-depth interviews. A prior report documented student outcomes from the Undergraduate Research Student Self-Assessment (URSSA) survey (Thiry & Laursen, 2009). This report focuses exclusively on findings from in-depth, ethnographic interviews with students. We will now describe each of the BSI's undergraduate research programs in greater detail.

UROP (Undergraduate Research Opportunities Program) is an established university program that supports UR experiences in all fields, not just bioscience. BSI supports this program by providing individual grants for students undertaking UR in life science-related fields. While UROP students' grants are provided through the BSI, the program as a whole is administered through the central UROP office, with whom the BSI cooperates. Thus the BSI's ability to change aspects of this program is somewhat constrained. However, because the BSI provides a higher stipend than the standard UROP stipend, the program does have some leverage; as a condition of funding, staff can require UROP students to attend training sessions, complete an evaluation or report, and meet other requirements that are specific to BSI-funded students. The UROP program was previously available only to upperclassmen, although it is now open to all full-time students, first-year to seniors. UROP students in this study tended to be more advanced or more experienced students. In addition to their research project, students are required to present a poster at the end of their experience and attend two training workshops on creating and presenting scientific posters.

The BURST (Bioscience Undergraduate Research Skills and Training) program was designed by BSI as an introductory research experience to meet the gap in UR opportunities for younger students. No previous research experience is required and preference is given to sophomores and juniors. Students who plan to graduate during the term of the award are not eligible for the program. Like UROP, the program is designed to be an intensive engagement, with a recommended commitment of 10-12 hours per week during the academic year and 30-40 hours per week for the summer term. BURST students participate in a series of workshops and trainings to prepare them for research work and enhance their laboratory skills and understanding of scientific research and writing. The workshops consist of a one-day orientation that covers safety, laboratory techniques, experimental design, and reading journal articles, followed by two additional sessions on writing scientific proposals.

Evaluation design and methodology

This evaluation study was designed to gather information on student outcomes from the two undergraduate research programs sponsored by the Biological Sciences Initiative. The study focuses on the gains students made from participating in research, student satisfaction with their research experience and their research program, and the influence of participation in research on their career or educational plans. The authenticity of students' research activities and the quality of the advising that they were received were also investigated. Particular activities (e.g. communication of research results) and interactions (e.g. with research group members) within the UR experience were also probed, to determine how student outcomes arise.

To complement survey data reported earlier (Thiry & Laursen, 2009), the present study was conducted using in-depth interviews. Interview protocols were designed to probe student gains and to explore the factors that might enhance or interfere with gains, such as advising and other interactions with the research group, the fit of the student's interest and talents to the project, their intellectual participation in "authentic" research vs. straightforward technical work, and the availability of resources and support, among others.

The evaluation questions addressed in this report are:

1. What gains do students make from their research experiences?
2. Are students satisfied with their research experience, and with the training and support provided by their programs?
3. What critical elements of the research experience can be identified interview responses (e.g. authenticity of experience, mentoring, etc.), and how do these contribute to student gains?
4. For each of these questions, can any differences in the UR experience and its outcomes be discerned for different student groups (if numbers permit)?: experienced vs. inexperienced UR participants, male vs. female participants, and white vs. minority participants
5. What can be suggested for further refinement of the program itself, and for further evaluation studies?

Previous Studies on Undergraduate Research

We will discuss the interview protocol and evaluation methodology in detail in the Methods section, but first we will discuss findings from previous research on UR that informed the development of the interview protocol and the study itself.

Ethnography and Evaluation Research (E&ER) has long been interested in student gains from UR experiences. Our previous work has provided insight about the types of gains to probe in this evaluation study and the factors that might be important in outcomes from the student UR experience. We will now summarize our findings from previous research on UR along with findings from other relevant studies.

Since 2000, E&ER has been engaged in a study of STEM undergraduates and faculty who did, and did not participate in summer UR programs at four liberal arts institutions with a strong history of UR. The study is both comparative—with student and faculty participants and non-participants of various types—and longitudinal, tracking both participating and non-participating students through their senior year and beyond graduation. Previous articles have described the benefits of UR as perceived by participating students (Seymour et al., 2004) and as compared to faculty perceptions of student gains (Hunter et al., 2007). A forthcoming article (Thiry et al., 2009) examines whether students' gains from UR can be achieved in other contexts, such as jobs, internships, or coursework. Collectively, these findings support the proposition that UR is an intellectual, personal and professional growth experience with many transferable benefits.

One of the main benefits to students from UR was the opportunity to engage in "thinking and working like a scientist." We noted in students a process that is encouraged by active engagement in research: many students improved their ability to bring their knowledge, critical thinking, and problem-solving skills to bear on real research questions; some students went further, gaining insights into how to generate and frame research problems; and a few developed a more profound understanding of how scientific knowledge is constructed.

However, the most distinctive characteristic of students' reports of benefits from UR was their focus on personal-professional transitions. Overwhelmingly, students defined UR as a powerful affective, behavioral, and personal-discovery experience whose dimensions had profound significance for their emergent adult identity, sense of career direction, intellectual and professional development. Students' comments in two categories ("personal/professional gains" and "becoming a scientist") described growth in confidence to do science, independence in their approach to both research and learning, responsibility for the direction and quality of their projects, and collegiality in their working practices.

Though the research literature on UR is sparse, our findings have echoed those found in other studies and also extended the previous research literature on UR, documenting many personal, professional, and affective gains from UR that had not been found in previous work. Previous work on UR has documented the educational and career gains from participation, including increased interest in science careers (Bauer & Bennett, 2003; Russell, 2005; Zydney, Bennett, Shahid, & Bauer, 2002), particularly for students from groups underrepresented in STEM fields (Nagda, Gregerman, Jonides, von Hippel & Lerner, 1998). Participation in research has also been shown to increase students' awareness of career options (Hunter et al., 2007; Ward, Bennett & Bauer, 2002); and enhance their preparation for graduate school (Alexander, Foertsch & Daffinrud, 1998; Hunter et al., 2007; Merkel, 2001; Russell, 2005).

The influence of undergraduate research on career choice is a subject of substantial interest but little consensus; it appears to depend strongly on the student group under study. Although our research has demonstrated that UR participation serves principally to confirm or clarify pre-existing career and educational goals (Seymour et al., 2004; Hunter et al., 2007), other studies have reported that participation in UR increases the likelihood that students will increase baccalaureate graduation rates (Kim, Rhoades, & Woodard, 2003), and increase the likelihood that students will pursue graduate school (Bauer & Bennett, 2003; Kremer & Bringle, 1990; Russell, 2005), particularly for minority students (Alexander, Foertsch, & Daffinrud, 1998; Barlow & Villarejo, 2004; Hathaway, Nagda, & Gregerman, 2002).

Perhaps more importantly, recent research on UR has begun to demonstrate the cognitive, personal and professional benefits to students of participation. Documented in our research and corroborated by other studies are increases in students' skills in communication (Bauer &

Bennett, 2003; Kardash, 2000; Ward, Bennett & Bauer, 2002), technical and laboratory work (Ward, Bennett & Bauer, 2002; Lopatto, 2004), teamwork (Ward, Bennett & Bauer, 2002), critical thinking and scientific analysis (Bauer & Bennett, 2003; Ishiyama, 2002; Merkel, 2001) and scientific research skills (Kardash, 2000; Lopatto, 2004). Through UR, students begin to take greater initiative and responsibility for their own learning (Seymour et al., 2004; Hunter et al., 2007; Bauer & Bennett, 2003; Lopatto, 2004; Rauckhorst, 2001; Ward, Bennett & Bauer, 2002) and gain confidence in themselves as independent learners (Hunter et al., 2007; Merkel, 2001; Rauckhorst, 2001; Russell, 2005, Ward, Bennett & Bauer, 2002). A few studies have addressed students' awareness of the nature and character of scientific research, finding that students gained an increased ability to cope with setbacks and ambiguity (Hunter et al., 2007; Lopatto, 2004; Merkel, 2001; Ward, Bennett & Bauer, 2002). Though UR clearly has many intellectual benefits, students have less often reported gains in desirable but difficult higher-order thinking skills such as identifying a research question, and designing and refining an experiment (Hunter et al., 2007; Kardash, 2000).

Finally, it is important to note that our group's previous research refers specifically to summer research experiences at liberal arts colleges. While these colleges have a long history of supporting and conducting undergraduate research, and represent, we believe, some of the best available educational experiences from UR, many more students participate each year in UR programs on research university campuses. We do not know to what degree our previous findings may apply to students' UR experiences in research universities, or how UR experiences differ in these two contexts. The present evaluation study may provide insight into the question of whether institutional type or demographic characteristics influence students' gains from the UR experience.

Methodology and study samples

The methods of data collection and analysis are ethnographic, rooted in theoretical work and methodological traditions from sociology, anthropology and social psychology. Classically, qualitative studies such as ethnographies precede survey or experimental work, particularly where existing knowledge is limited, because such studies can uncover and explore issues that shape informants' thinking and actions, and estimate the relative significance of these issues. The ethnographer generates hypotheses for the experimentalist to test and questions for the survey investigator to ask. The development of the Undergraduate Research Student Self-Assessment Survey (URSSA) was informed by just such a process; qualitative interview findings were used to develop analytic categories to quantitatively assess students' gains from research. Findings on BSI programs from the URSSA instrument were documented in a previous report (Thiry & Laursen, 2009).

The interviews were minimally structured so as to encourage interviewees to reveal their own perspectives instead of tailoring their input in response to categories introduced by researchers. The protocols were developed and continually refined in response to emergent issues, so that insights gained from early interviews could be explored further in subsequent interviews. To preserve confidentiality and anonymity, the names of interviewees were known only to the interviewers. In reports of findings, no interviewee is identified, and illustrative quotations are edited to ensure anonymity. The study was approved by the Human Research Committee at the University of Colorado at Boulder.

Interview tapes were transcribed *verbatim*. The transcripts were submitted to *N'Vivo,* computer software that allows for the multiple, overlapping, and nested coding of a large volume of text with a high degree of complexity. Each interview transcript was searched for information bearing on the research questions. Information is typically embedded in speakers' accounts of their experience rather than in abstract statements. Segments referencing issues of different type or perceived importance are tagged with code names. Codes are not preconceived, but empirical—each new code references a discrete idea not previously raised. Because answers to the same question may differ in character or cover different issues, codes are developed to describe the nature of the response given, not the question asked. Interviewees also offer information in spontaneous comments, narratives, and illustrations. They often make several points in the same passage, each of which is separately coded.

Each coded file contributes to the data set of both coded observations and the defined codes that label them. Groups of codes that cluster around particular themes are assigned to domains (Spradley, 1980). This interconnected and branching set of codes and domains grows into a codebook that, at any moment, represents the state of analysis. The clustered codes and domains and their relationships define themes of the qualitative analysis. In addition, the frequency of use of particular codes or domains can be counted for the sample or for important subsets (e.g. by gender). Together, these frequencies describe the relative weighting of issues in participants' collective report.

In this report, we have reported these frequencies in terms of both the number of participants' observations, or comments, within a category and the number of individuals raising a particular topic. We have generally differentiated these two types of frequencies in the report by referring to the *number of comments,* (i.e., counting the number of participants' statements within a particular category), or the *number of students, (*i.e., counting the number of people who discussed a particular topic). Because of the nature of loosely structured interviews (as opposed to the uniformity of survey questions), these numbers do not represent a true quantitative measure of respondents' feedback. Questions are not asked in the same order or with the same wording in every interview; and some topics arise spontaneously and thus are not represented in every interview. Moreover, a low frequency does not necessarily reduce the importance of an observation—for example; an explanation given by a single individual may be particularly insightful in explaining and relating observations made by others. Thus, the numbers should not be used to make statistical inferences, but are nonetheless useful in that they indicate the general magnitude of trends.

Procedures for obtaining the interview samples

We conducted interviews with BURST and UROP students in spring 2007 and spring 2008. BURST interviews were all conducted in spring 2007; because of a poor response rate from UROP students, we conducted additional interviews in spring 2008. Interviews were conducted near the end of the academic year so that students would have at least two semesters of research experience to draw on during the interview.

All research students within the two programs were invited to participate in an interview. BSI staff provided the evaluators with lists of BURST and UROP research students and their contact information. We sought to conduct 15-20 interviews with students from each program. We also sought to achieve a sample that was relatively balanced as far as gender, year in college and major; however, the BURST program was disproportionately female, so gender parity was not possible. E-mail invitations to participate in the interview were sent to each student. A total of four e-mail invitations were sent to each group; an invitation was sent every two weeks at the end of the academic year. The original interview sample consisted of 18 BURST and 18 UROP students; however, the recording equipment failed for three of the UROP interviews and interviews could not be transcribed for analysis. Therefore, the final interview sample consists of 18 BURST and 15 UROP interviews.

Descriptions of the interview samples

BURST and UROP students undertook a variety of life sciences majors; MCDB was the most common major (36% of students). Almost a quarter of students were Integrative Physiology majors and one-fifth of students were Biochemistry majors. Psychology and Ecology and Evolutionary Biology were also represented. Some students also had double majors or minors in complementary life science fields; only one student had a second major or minor in a non-life sciences field.

Given the disproportional number of women in the BURST program, the interview sample was 64% women and 36% men. This disparity was taken into account when analyzing interview data for gender differences. Perhaps due to the gender discrepancy of the sample, there were few gender differences in our findings. All students came from racial and ethnic groups that are well represented in the sciences, either Caucasian or Asian. The relatively new NIH Scholars program for diversity in the biosciences provides research experiences for students from underrepresented groups in the life sciences. The majority of students also held advanced class standing: 42% of students were seniors, 33% were juniors and 24% were sophomores.

Many students—including even a few from the UROP program—had a moderate amount of research experience. Most students (72%) had 2 semesters of research experience. Fifteen percent of students had three or four semesters of research experience, while nine percent of students had five or six semesters of research experience. One student had conducted research for eight semesters. Although some UROP students had only completed two semesters of research experience, overall, UROP students were more likely to have engaged in summer research. No BURST students had participated in summer research, while 53% of UROP students had participated in one summer of research, 13% had participated in two summers and 7% had participated in three summers. Collectively, students from the UROP program had more research experience than novice BURST students.

Findings

We discuss interview findings in two major sections: program outcomes and research outcomes. In the program outcomes section, we discuss students' overall satisfaction with their research programs, including the application process and financial stipend, support from program staff, and program workshops. These outcomes are of internal use to the program in adjusting or refining its activities. In the research outcomes section, we discuss students' motivations for participating in research, their gains from the research experience, the authenticity of their tasks and activities, and the quality of advising they received. We have identified several key areas of support provided by research advisors, including intellectual support, personal/emotional support, and socialization into the profession. These outcomes are of interest both as feedback to the program and more broadly as indicators of the potential and limitations of UR as an educational strategy. First, we discuss programmatic outcomes.

Program outcomes

BURST

Findings from the BURST interviews corroborated BURST students' responses to the URSSA survey (Thiry & Laursen, 2009). In interviews, BURST students indicated that they were highly satisfied with the support they received from the BURST program, particularly from program coordinator Lynn Wolfe. Most students found the program workshops to be beneficial learning experiences, while some students did not perceive the workshops' utility and relevance.

The application process

There were few comments about the application process, mostly positive. Almost all BURST students who commented on the application process noted that it was easy and simple; however one student thought the application was too long and another found it confusing. The comment below is typical of those from students who appreciated the simple application process.

> *I thought the application process was very user-friendly, considering some of the other applications I've had to do. It was very simple, and to the point, and I appreciated the lack of fluff. (BURST student)*

As noted in the results from the URSSA survey (Thiry & Laursen, 2009), the financial stipend was quite important, particularly for students who were financially independent from their families. Two self-supporting students mentioned that the stipend was not enough to pay their living expenses, and both held other jobs outside of research.

> *So just the frustration that there's not more money to put in research…. I'm an independent student that also has to pay bills. And this is, I not only see it as a research*

opportunity, but I also do this as my job… And there's not enough money to support enough people at a sustainable income level to live in Boulder. (BURST student)

Nevertheless, the BURST stipend was important for students who would otherwise be unable to engage in research on a volunteer basis for financial reasons.

I could not have done research in the school year without BURST. Financially, I help support myself in college, and I need a paying job, so without the BURST program I simply would not have been able to continue my research. (BURST student)

Guidance and support from program staff

BURST students were highly satisfied with the guidance and support that they received from the BSI and Lynn Wolfe. Every student comment regarding Lynn or the BSI was positive; there was not a single negative or mixed comment. In particular, students mentioned that Lynn was approachable, accessible, friendly, helpful, responsive and supportive. Lynn also assisted BURST students with lab and research group selection, and with their UROP applications. Following are a few typical comments from BURST students about this support:

I feel like if I needed help with any research thing, I could ask, or send an e-mail to Lynn, and she would help me out as much as she could. So I feel like [the BSI] was a really good environment, and people seemed really helpful. (BURST student)

[Lynn's] been extremely helpful, and very open to me, whenever I've talked to her. I have had just an amazing experience working with her. She's been over the top, gone beyond what I've expected. I've had a very positive experience. (BURST student)

Lynn was very nice, very helpful and always available, and she answers e-mails faster than (LAUGHS) you can blink an eye! She gets back to you right away with whatever you have a question about, and she's just a very nice woman, and very, very helpful. When we were approaching the UROP deadline, she offered to proofread, and offered to help, and gave her phone number, if we had last-second questions. And just was very helpful, and very open to assisting the BURST students however she could. (BURST student)

Therefore, students felt intellectually and personally supported by the BURST program. Students reported that Lynn Wolfe was approachable, helpful, and friendly. They saw her as a resource both for support in their current research experience and for assistance with UROP proposals to continue their research work.

Workshops

While many BURST students reported that program workshops enhanced their learning, some students had mixed responses regarding the value and utility of the workshops. Overall, students were evenly split in their feedback on the program workshops. One-half of students reported that the workshops, particularly the introductory workshop, were a "good refresher" of basic lab skills and techniques. However, one-half of students felt that the laboratory skills training was not relevant to their particular research placement; most of these students held Integrative Physiology research positions, working with animal or human subjects.

Some students appreciated the introductory laboratory training and felt it strengthened and reinforced their basic laboratory skills. These students utilized the training in their research placement and noted that their learning also transferred to their coursework.

> *The first training session was something about, calculating moles, and it refreshed my memory. So the next day when I went to the lab, and my research supervisor was explaining to me all the stuff, I was like, "I know everything, we just did it yesterday." (BURST student)*

> *We had one in the very beginning and it kind of taught us how to keep a lab notebook and what sorts of things were important. And it also reviewed a lot of the common things you have to do in lab, which is make solutions and reagents and how to dilute things. And so it was a good refresher with everything that I've learned so far with my other classes. (BURST student)*

Many students were unfamiliar with the requirements for a research lab notebook and found the training in keeping and organizing a lab notebook to be informative and beneficial.

> *[The training in keeping a lab notebook] helped a lot because I didn't know anything about that before. So that gave me a little background before coming in here and just being given a notebook. (BURST student)*

Some students also reported that safety training prepared them for their work in the lab.

> *Before we could start our work we had to do, like, hazardous materials training and animal training if we were working with animals and general safety training things. So they really prepared us for starting work. (BURST student)*

Besides the introductory session, the BURST program offered several other workshop sessions. Some students appreciated learning about research opportunities beyond the BURST program.

> *I think there was another workshop we had at the beginning, where we talked about other research opportunities after the BURST Program…. That workshop was pretty helpful because, I remember at the beginning of the semester trying to research the BURST and UROP, and how to get funded. And even outside of that, it's pretty hard to compile all of the different websites that are all over the place. And she had already compiled them for us. (BURST student)*

While laboratory skills training reinforced students' existing knowledge, library skills training often introduced new knowledge and skills. Students learned how to navigate the library and utilize databases to find information related to their research.

[Library skills training] was useful. At the time I was reading a lot of articles, and just trying to get acquainted with the research that's already been done surrounding the experiment that I was getting involved with. So, that was definitely helpful. (BURST student)

The session I went to for using the library as a resource, I thought was really helpful. And those are skills that once I've learned them, I've used since then. So, I'd say, personally, that's probably been the most useful session that I've attended so far… I've used them for researching class assignments, and also for the lab. It's just been very helpful overall. (BURST student)

On the other hand, some students found that program workshops, particularly laboratory skills training, were not relevant to their research experience. These students—many of whom were in Integrated Physiology or Ecology and Evolutionary Biology laboratories—reported that the training focused primarily on molecular biological techniques to the exclusion of other research techniques in the life sciences. Some students requested that the BSI offer an optional workshop on techniques involving human and animal subjects, or field research. A few students also felt that they were already familiar with the techniques presented and did not need more exposure to those procedures. The following comment is representative of these assertions.

And a lot of the other research assistants that were there, were dealing more with microbiology, chemistry, DNA, or spectral analysis. And so they catered the program more to that, with working in an actual biology or chemistry lab versus a human subjects lab. So, the workshops, for me personally, I didn't think were particularly effective, just with the amount of experience that I had already gained [in my lab group]. (BURST student)

Overall, although students were divided on the utility of their training in laboratory techniques, there was general consensus that training in keeping a lab notebook and library skills was transferable to their research experience. Training in library skills also transferred to students' coursework.

BURST students also attended a writing workshop to support the development of a research proposal for admission to the UROP program. Overall, students found the workshop to be informative and felt that it enhanced their scientific writing skills. Students also appreciated feedback on their drafts. However, a few students noted that there was not enough time between the workshop and the UROP application due date, making it difficult to complete the proposal on time. Students received valuable scientific writing skills from the proposal workshop that they would not have received from their research experience alone.

The proposal-writing was really helpful, just because I had no idea how to even go about this. And without that workshop, I wouldn't have. (BURST student)

And the [proposal writing workshop] was very helpful. And I'm totally glad we went and had those sessions, and got all the material, and the papers we got, and the stuff we went over, to do the UROP proposal. Because ultimately when it comes down to doing research, if you can't write out a proposal, you're not gonna survive as a researcher. Because that's

> *ultimately what they do. So it's a good taste, I think, to write out that proposal… because that's how you survive, and make grant money, and keep your lab going. (BURST student)*

Student advice to the BURST program

Students were also asked if they had any advice for the BURST program. In keeping with their feedback about the relevance of the workshops, some students recommended making the seminars optional or having a series of seminars for different areas of research so that students could attend the training that is most relevant to their research placement

> *Multiple seminars that are more focused—and then require the students attend the seminar that is most associated to their type of research. So maybe just to split it up and have smaller groups of people, where people could talk about their lab experience, and have someone in that field talk to them about what they're doing. (BURST student)*

Students also discussed BURST's visibility. On the URSSA survey, only a few students indicated that they learned about their research program through formal means or program announcements. Likewise, in interviews, some students noted that BURST could benefit from more marketing and a higher profile on campus. Students found the program to be very valuable and would like to see it become more prominent on campus.

> *I think undergrads coming in should know more about [the BURST program]. It should be advertised more, and it should be one of those things that CU is really proud of. I just think it should be made known to undergrads a lot more. (BURST student)*

Finally, some BURST students requested more interaction among program participants. These students wanted more opportunities to socialize and to learn about each other's projects in an informal setting.

> *I think it would have been nice to have more of a social time to talk about everyone's research, and maybe have a project, where everyone just briefly presents on what they're doing in their lab. So that everyone can see what else is going on on campus. (BURST student)*

In sum, the vast majority of BURST students were satisfied with the support they received from the BURST program. Students felt that the BURST program staff was responsive, supportive, and organized. Most students found the BURST workshops to be helpful to their learning as well as a "good refresher" or introduction to the research experience. However, a few students did not find value in the workshops, particularly the laboratory skills training, and felt that they did not gain new knowledge or skills. A few students, particularly those working with animal or human subjects, felt that the training was not relevant to their own laboratory placements or needed research skills. Therefore, we suggest that BURST program staff inform students about the learning objectives of each program workshop and its importance in developing scientific skills and knowledge. The BSI could also re-organize the laboratory skills training into a series of workshops focused on skills relevant to various life sciences fields or methods, and allow students to select a set of workshop(s) most appropriate for their particular research position.

UROP program

For the most part, UROP students' comments echoed those from BURST students. UROP students' interviews also corroborated their responses to the URSSA survey (Thiry & Laursen, 2009), suggesting that the survey has validity in identifying programmatic outcomes.

Like BURST students, UROP students were satisfied with the support they received from the program and from Lynn Wolfe. However, UROP students reported less interaction with program staff than BURST students. UROP students also benefited from that program's emphasis on scientific communication skills.

Application process

Like BURST students, UROP students were satisfied with the application process. In addition, UROP students noted that the proposal requirement benefited their learning and development as scientists. Most students had never written a proposal and this "real-world" exercise helped them to feel more comfortable with this element of scientific practice. Students also strengthened and improved their scientific writing skills.

> *It was helpful 'cause the HHMI grant proposal is the first one I've written, and, I got a feel for that. It helped me with my scientific writing a lot more, 'cause I hadn't worked on that before, at all. (UROP student)*

Financial stipend

Students were evenly split on the value of the financial stipend. Half of students were satisfied with the stipend and reported that it was beneficial to be paid for their work.

> *It's really nice to get a chance to get funded, to get paid to do research as an undergraduate. It's a cool opportunity to have. (UROP student)*

On the other hand, some students, particularly a few financially independent students, reported that the stipend was not enough to pay their living expenses in Boulder. These students noted that they had to work extra jobs in order to support themselves, interfering with their ability to spend time on their research projects. One student mentioned that she might not be able to continue with her UROP placement for financial reasons.

> *When I first started working in this lab, I had two jobs and then I quit my second job, and I've been working in this lab trying to make sure that I can get this project done. Because … when I had two jobs, …I was always tired and I never wanted to work on my project. So I quit my job, and now I'm just trying to focus on making sure that I get this done, and that I don't have it hanging over my head forever. But financially, I think it might be a little bit too hard for me to swing paying rent in Boulder and working for a very minimal*

amount of money, even though it's not taxed. It's still not as much money as I could be making [elsewhere], so I don't know if I'll stay. (UROP student)

Program staff

UROP students were highly satisfied with their interactions with program staff but reported less frequent interaction with program staff than BURST students. In fact, nine students noted that they had minimal interaction with program staff. Nonetheless, all of UROP students' comments about interaction with BSI staff were positive. Like their peers in the BURST program, UROP students commented that Lynn Wolfe was organized, supportive, accessible, and responsive. Two students mentioned that they would appreciate more contact with Lynn Wolfe. The following comments reflect students' satisfaction with this support.

I think [Lynn] did a great job. With organizing everything, and bringing people in that were really good at explaining what the session was about. I think she did a pretty good job. (UROP student)

I met with Lynn once last semester. …Lynn had sent out an e-mail at the beginning, if you need any guidance, and that sparked me to seek her guidance about grad school. …And I was in the midst of applying for grad school and I talked to her and asked her about stuff from a perspective of someone who's done it and sees so many students. So she was really good in terms of that. (UROP student)

Workshops

UROP students were also mixed on the value of program workshops. Like BURST students, some UROP students found the workshops to be beneficial, while others felt that the workshops were geared for beginners. Some students also felt that the workshops were not relevant to their particular lab placement and the skills and techniques useful in their research experience.

The topics and the speakers didn't necessarily apply to my field. A lot of it I had seen. I had taken scientific writing classes. (UROP student)

Some UROP students felt that the workshops were intended for novices, and were not relevant for advanced students.

A lot of them seemed very rudimentary and basic…. I feel like a lot of the workshops didn't really apply to anything I was doing in the lab, so it was kind of hard for me to find meaning in them. (UROP student)

On the other hand, some students found the workshops to be very beneficial, particularly the workshops that focused on communication skills and disseminating research results. As the following comments show, students appreciated an introduction to scientific writing and presentation techniques and the specific suggestions and guidance from workshop presenters.

> *They were really helpful–like, really helpful. We had a "How to write an abstract" and "How to design a poster," which really stuck out to me. They brought in faculty from around CU Boulder, and went over the main points about an abstract, and how a poster should be arranged, roughly what percentage to devote to each section of your research, and things like that. So I thought those two sessions were, I thought, really great, and helped out a lot. (UROP student)*

> *There was one where he did a PowerPoint presentation regarding what the poster was composed of in each segment, and what was the best way to write them. Or how to be creative on them, or what works well, and what doesn't work well in the poster. And I think that was a good insight, 'cause I don't have any idea what I was doing, so having any type of advice was good on that area. (UROP student)*

Students also appreciated learning about ethics in writing and publication, a topic that was new to most of them. As with the proposal and poster workshops, students felt that training in publications and ethics helped to prepare them for a scientific career.

> *I think it was definitely just good to go and listen to it and, and just get a good understanding of all of it. I think all of that is going to be important in writing and doing all the research. I think that was definitely a very important one. (UROP student)*

Poster session

The culminating activity of the UROP program is a poster session at the end of the term. As with the proposal and abstract requirements, the poster requirement introduced students to a realistic form of professional dissemination and helped them to develop scientific communication skills. Students felt that presenting a poster provided an important glimpse into professional practice and prepared them for presentations at future professional conferences.

> *Doing the poster was pretty helpful, because it was the first time I'd ever made a scientific poster. I feel like I probably would be doing quite a few of those in the future. Because this was the first time I'd ever done it, I was getting a pretty cool look at how it's made and what a scientific poster entailed and what needs to go on it and how to present them at a conference and whatnot. (UROP student)*

Because creating a poster was a new experience for most students, some students felt that the scheduling of the poster workshop could be improved. Students felt that it would be helpful to have a final workshop closer to the actual presentation date so they could get feedback and constructive critique on their draft poster. A few students envisioned that this would provide an opportunity to critique each other's drafts and get ideas from peers, while other students envisioned a smaller group setting that would allow for more individual feedback on their draft posters from an expert.

In fact, a common theme among students was the desire for more scholarly feedback and critique of their posters. Students mentioned that they would gain more from the poster presentation if more faculty and graduate students attended. The attendance of more senior scientists would allow for students to engage in scholarly, collegial discussions with expert scientists. In the following comment, a student suggests that the poster session could benefit from more structure and opportunity for scholarly dialogue.

> *I kind of wish we could have reworked the poster session a little bit, because I kind of felt like it was just sort of a free-for-all. Everyone was sort of there with their posters and people were just circulating but it was a, "Well this is interesting, this is interesting, this is interesting." And not a genuine sort of discussion between somebody who's interested, some observer, and the person who created the poster… I don't know, get a few more postdocs or faculty there, open it to the public or at least try to foster more dialogue there. (UROP student)*

In keeping with their comments about constructive feedback and dialogue about their posters, a few UROP students also desired to create a stronger community of scholars among participants. We should note, however, that some students did not express a desire for more interaction with their UROP peers. Nevertheless, the following comment reflects the desire of a few students to have a scholarly community among UROP students.

> *I think having a community of researchers is really helpful, 'cause you see the grad students, and they're all friends, and they help each other with their research. They'll troubleshoot together and stuff. And it would be cool to have something like that with our undergraduates, with the few of us who do research on campus; it would be cool to have a forum, where we could talk about stuff together. (UROP student)*

Other students suggested an occasional discussion group, similar to a journal club.

> *I think that maybe having conversations with other students, like a forum where maybe we're all required to read some paper, and we're gonna discuss it in small groups or something once a semester. That's not that much to ask. If we were to discuss an issue in health, in medicine, or in, research, or something that has been controversial in the past, that'd be cool. (UROP student)*

Overall, UROP students' comments about programmatic outcomes were similar to those of BURST students. UROP students were highly satisfied with their interactions with program staff, though they reported less frequent interaction than BURST students. Similar to BURST students, many UROP students found program workshops to be beneficial to their learning, though some did not. Students in both programs found the workshops focused on scientific communication to be useful in introducing essential knowledge and skills for the dissemination of research results; however, some students found the laboratory skills training to be of less value.

We thus suggest that program staff articulate more explicitly to students the learning objectives for program workshops and activities to communicate the importance of this knowledge for future scientists. The BSI could also re-organize the laboratory skills training into several workshops focusing on specific areas of life sciences research. Students could select the workshop that focuses on the techniques and procedures most relevant to their particular research placement. While there does appear to be some value in the scaffolding of basic workshop topics such as safety and communication, technical sessions could be offered jointly to BURST and UROP students to attend as relevant to their research area. Selecting these sessions would also be a fruitful topic for students to initiate early conversation with the research advisor.

UROP students also desired to engage in more scholarly dialogue and receive more constructive critique on their posters and abstracts. By encouraging more faculty and graduate and postdoctoral researchers to attend the poster session or formalizing a mechanism for more feedback from "experts" in their fields, students might receive an important introduction to the communication of scientific results and the process of dialogue and critique within the scientific community. However, this unmet need also speaks to the fact that student researchers do not see their peers as helpful resources. More frequent opportunities to present their research topic and progress to date (as indeed some students suggested) would help students to develop familiarity with each others' projects and greater comfort in giving and receiving critique, all of which would enhance their ability to ask good questions and engage in more informed discussion with peers at the poster session. A side benefit would be to foster the social and intellectual interactions that students suggested. Our prior research shows that the ability to participate in give-and-take scientific dialogue is a very valuable skill for students but requires substantial practice.

Research Outcomes

Now we discuss specific outcomes from the research experience itself. We first discuss students' motivations for participating in research and then we will describe students' gains from their research experience. We also discuss the authenticity of students' research experiences and the benefits they received from interactions with their research advisors.[1] We have identified three primary ways in which research advisors support their UR students: socialization into the profession and the discipline, intellectual support on the research project, and personal/emotional support. We now address students' motivations to engage in research.

Students' motivation to participate in research

Students' motivations to participate in research were primarily intrinsic, such as interest in the topic, rather than a desire for extrinsic credentials, such as letters of recommendations or to enhance medical or graduate school applications. BURST students expressed more extrinsic reasons for engaging in research than UROP students. BURST students, on the whole, were more interested in medical or healthcare careers and somewhat less interested in and committed to scientific research or graduate school attendance.

The top three reasons for participation in research for UROP students were:

- Interest in science/research topic, (40% of UROP students, n=6)

[1] We use the term "research advisor" or simply "advisor" to refer to the person who supervises a research student. This may be a graduate student, postdoctoral researcher, other research scientist, or faculty member. Our term emphasizes this individual's role, rather than their status.

- To find out what research is like, (27% of UROP students, n=4)
- To clarify career or graduate school plans, (20% of UROP students, n=3)

The top three reasons for participation in research for BURST students were:

- Enhance résumé or graduate/medical school application, (33% of BURST students, n=6)
- To find out what research is like, (28% of BURST students, n=5)
- Gain job or graduate/medical school preparation, (17% of BURST students, n=3)

Although BURST students were somewhat more instrumental in their motivations to pursue research than UROP students, both groups were highly motivated by the desire to learn more about research and to find out what it is like in practice.

> *I wanted the experience of learning what kinds of things go into research. Just the whole process of coming up with the research question, and then the different steps that you take to collect data, and analyze it. And then publish your results, so that you can help people. (BURST student)*

> *I just wanted to get into a lab, and I really wanted this. I was very curious about what type of research was going on in the biochemistry world, and I've really been exposed to that. (UROP student)*

Perhaps due to their more advanced status, UROP students were more motivated by the desire to explore career or graduate school options. UROP students were more likely to be actively exploring career options and were less committed to medical careers than BURST students.

> *One of the reasons that I wanted to start research was because I was considering doing a Ph.D. And now I think that I probably would do it if I was given the chance to, so I enjoyed the experience. (UROP student)*

> *I've always been interested in neuroscience or science in general, and when I started psychology at CU, a lot of psychology at CU was geared more towards clinical. And I hadn't felt like I was leaning towards clinical; I was looking for, other things I could do. (UROP student)*

BURST students, in particular, were also driven by the desire to augment their résumés or medical/graduate school applications. However, the following student also perceived a culture of participation in undergraduate research on campus and faculty had encouraged him to pursue research to obtain valuable preparation for medical or graduate school.

> *I knew that I wanted to go to medical school, and my advisor definitely suggested research as something good to do in your undergraduate. Plus CU's got such a good research program that, being in the sciences, any professor encourages you to take part in the research programs. (BURST student)*

Gains from the research experience

We now discuss students' learning and development from their research experience in terms of the six categories of gains identified in our four-college study: *thinking and working like a scientist, personal/professional gains, becoming a scientist, skills, enhanced career and graduate school preparation, and clarification of career aspirations and interests* (Hunter et al., 2007).

BSI students' gains from their research experiences paralleled those reported by the students in our study of four liberal arts colleges (Hunter et al., 2007; Seymour et al., 2004). Indeed, 91% of BSI students' comments referenced gains achieved from the experience, termed "positive" observations, while only 9% of comments were negative/mixed, reflecting gains not achieved. By "negative" observations, we do not mean negative in tone, but rather students' explicit statements about what they did *not* gain from research. What we call "mixed" observations often described areas in which students reported limited or weak gains, and did not yet feel confident and independent. Mixed observations also included comments in which students asserted that they had made gains but, by their descriptions of those gains, we judged that they had not made the gain at a developmental level appropriate for college students. Because there were few mixed observations in our analysis (only 8 out of 685 total gains comments), we have combined the "negative" and "mixed" comments into one group. Overall then, the proportion of positive comments from BSI students equals the proportion of positive comments from students in the four-college study (Hunter et al., 2007). Thus we can conclude that much like liberal arts colleges, UR at research-extensive universities offers ample opportunity for students' intellectual, personal, and professional growth.

Although BSI students as a whole reported numerous gains from their research experiences, we identified some differences in gains between BURST and UROP students. For example, BURST students made 70% of the negative and mixed comments, largely about communications skills and higher-order intellectual outcomes. These differences in gains reflect programmatic differences and the varying levels of research experience between BURST and UROP students. Few research students in general—much less novice researchers such as BURST students—make gains in higher-order thinking skills, such as experimental design or identification of a research question (Hunter et al., 2007; Kardash, 2000). The present study demonstrates that gains in higher-order scientific thinking skills develop over time through authentic research experience in collaboration with advisors and peers.

On the whole, the vast majority of students' comments reflected gains made from the research experience. BSI students, from both the BURST and UROP programs, reported the greatest gains in intellectual growth—the category we call "thinking and working like a scientist." BSI students also reported strong gains in professional growth—the category we call "becoming a scientist"—and skills. Career gains were less important to students, in part, because most were still undecided about their educational and career paths. As noted previously, the nature of students' comments within all six categories of gains describe their progression of learning, development, and personal growth as they transition from novice to more advanced status.

Thinking and Working like a Scientist

The category “thinking and working like a scientist” encompasses gains in the application of scientific knowledge and skills, understanding the process of scientific research, understanding the nature of scientific knowledge, and extending and solidifying conceptual and theoretical understanding of the field. Students reported the largest proportion of positive gains comments in this category, comprising 30% of all BURST students’ positive observations and 24% of all UROP students’ positive observations. Along with “skills,” the intellectual gains of “thinking and working like a scientist” comprised the largest category of negative/mixed comments.

Thinking and working like a scientist: Application of knowledge to research work

Through research, students learned to apply their prior knowledge to a research question or problem. They gained critical thinking skills and learned data collection and analysis techniques. Both BURST and UROP students reported gains in data collection skills and in applying critical thinking and problem-solving skills to a research problem.

> *I would say [I gained] critical thinking. Because before I did this research, even in class, if anyone tells me, "This happens," I would be like, "Okay, this happens." I wouldn't question why this happens. After doing research, I think I have realized that I have been questioning, "Why does this happen?" "Experimentally, why does this happen?" And all those things. (BURST student)*

Experiencing setbacks or failures in the lab often enhanced students’ problem-solving skills as they tried to determine why an experiment failed or did not produce the expected results.

> *I definitely think I learned a lot of problem-solving, because in the beginning and most of this past semester, things haven't been working very well. So I've been trying to figure out, why things aren't working and so I think I learned a lot of problem-solving. (UROP student)*

Although almost all students reported gains in learning data collection techniques, fewer students reported gains in data analysis methods. Advanced students, typically UROP students, reported stronger gains than BURST students in data analysis and interpretation (53% of UROP students and 27% of BURST students reported gains in this area).

> *As far as all the behavioral data, I had to do all the graphs. I had to learn how to enter it all into Excel. I had to learn how to analyze the data. I was given like a skeleton , it had the programming specifically for the numbers I had to put in, and then, how to calculate it a certain way. So, I had to put in the raw data, and then I had to make sense of it somehow. I had to learn how to do all that, and that was pretty tricky. That took a lot of work and a lot of patience. (UROP student)*

> *Analyzing data is a lot of what I do, too, and then trying to figure out where something can go wrong or hypothesizing about what went wrong or what went right. (UROP student)*

However, not all students had the opportunity to learn data analysis methods. Some students (about 1/3 of the sample) worked on projects that had not reached the data analysis phase yet; some were involved in setting up a new project and others were still immersed in the data collection phase. But some students worked on teams that were actively analyzing data, yet did not have the opportunity to learn or try out analysis techniques, as indicated in the comment below. For the most part, BURST students less often had opportunity to learn data analysis methods.

I've entered data, but I haven't actually made the graphs. I kind of know how to, just because I've taken a statistics class, and then in our biology class we're expected to do that. But I think [my advisor] uses a different program than I do anyway, so I don't know how she does it, and it's on her computer. (BURST student)

Few UR students learn about experimental design or have the opportunity to design their own experiment during their research experience (Hunter et al., 2007; Kardash, 2000). Likewise, few BSI UR students reported gains in higher-order scientific thinking skills, such as experimental design or identifying and refining a research question. Only advanced students gained these higher-level scientific thinking skills (6 UROP students reported gains in this area). These students learned about experimental design through participation in discussions about research design in lab meetings, or by providing input into the design of their own research project. One student reported that she designed her own experiment independently, while the other five UROP students reporting gains in this area designed experiments in collaboration with their research advisor or the project P.I.. Students also learned about experimental design and research methodology from journal articles. In the comment below, a UROP student described the way in which she provided input into the modification of her experiment, although she did not generate the research question herself. [2]

The original idea about our hypothesis, or what we expected to see, was ____. They'd been kind of thinking about it for awhile, but they hadn't tried to do it experimentally. And so they were like, "Well, maybe you could try this." I was like, "Okay." So the original idea was obviously theirs, but then as I did more and more, I would tweak the experiment, to what I thought might yield better results. (UROP student)

Other students described generating a research question in collaboration with their advisor or P.I. In this case, senior personnel had considered undertaking a specific project for several years, yet the student brought the research idea to the team. The research team then helped the student craft his idea into an experiment.

Interviewer: Did you have some input into the design of this experiment?

UROP student: Right, yeah, I did. I looked at a couple of papers that did similar work and then brought those ideas up to [the P.I. and my advisor] and they agreed and disagreed with a few things, and so we changed and found what works best. It was a joint effort. I had interest in it and they had been thinking about this project for a couple years actually. But I brought up the idea and they were just like, "Oh yeah, that's definitely something that we were hoping to get done." (UROP student)

Overall, few students participated in the development of an experiment or generating a research question, and those who did, did so to varying degrees. Only advanced students had a

[2] A portion of this excerpt has been deleted to maintain the confidentiality of the participant.

sophisticated enough understanding of research methodology and the theoretical concepts underlying their project, to propose a research question or design an experiment.

Additionally, few students made gains in developing a complex epistemological understanding of the open-ended nature of scientific knowledge, a finding consistent with our prior research (Hunter et al., 2007). Again, UROP students reported stronger gains in developing this understanding than BURST students (26% of UROP students and 11% of BURST students reported gains in this area). When students had ownership over an experiment, they began to develop an understanding that scientific knowledge is falsifiable and subject to revision. Students also began to appreciate the ambiguity of science, as they no longer viewed it as strictly "black and white."

> *Before I started doing my own research or working with people who are researching, I would, as far as science classes go, you listen to what the teacher says or you read the textbook and you just take that for granted as being, that's the way it is. But I never really thought of how that information came about…. Before working in a research lab, I definitely felt that whatever was in the textbook was 100% accurate. But now, especially through conversations with grad students and postdocs, they told me that that's not necessarily the truth at all…. There could be a bunch of different explanations for a simple phenomenon. (UROP student)*

A failure to make gains in the application of knowledge to research work

Ten percent of students' comments within the "thinking and working like a scientist" category were negative or mixed observations, indicating a complete or partial failure to make a gain. While relatively rare, we will still discuss these comments because they are instructive about the types of research activities and lab interactions that can lead to a failure to make these intellectual gains from the research experience.

Almost all of these negative and mixed comments referenced a lack of growth in students' ability to apply their knowledge to a research question or problem. Students had not gained the higher-order scientific thinking skills of data analysis and interpretation, or experimental design. A few students had worked on projects that had not progressed to the data analysis phase, but most comments came from students who simply did not have an opportunity to engage in data analysis. In the comment below, a student describes how his advisor has not provided the opportunity to participate in data analysis or think more deeply about the experiment.

> *[My advisor] keeps us really busy, and so there's not much time to ask exactly what the results are... 'Cause she decided we'll do all the tissue [prep] and all the studying up for the experiment, do the experiment, and once the data comes around she's the one that analyzes it. So I have not been in that process yet. (UROP student, negative observation)*

In conclusion, both BURST and UROP students reported strong gains in critical thinking and data collection skills. UROP students were more likely to develop analytic skills. A minority of UROP students also made advancements in understanding the nature of scientific knowledge and the nuances of experimental design. A small fraction of students did not have the opportunity to engage in data analysis or problem-solving on their project.

Thinking and working like a scientist: Increase in conceptual or theoretical understanding of the field

Students also reported increases in their conceptual or theoretical understanding of their field or discipline. Unlike the prior sub-category of applying knowledge to research work, BURST students made the majority of these observations (77% of all comments about conceptual understanding). There was only one negative observation within this sub-category.

As novice researchers, BURST students needed to learn about the field and their discipline, and they had so far taken fewer advanced life sciences courses than UROP students. The following comment by a BURST student describes the way in which he has learned basic techniques and concepts from his research advisor.

> *I've done quite a bit of molecular biology with [my advisor], actually preparing DNA, and RNA, and making gels. That's actually really a fun experience to do with him, 'cause he's an excellent molecular biologist. So we just hang out, and he explains to me all about how the DNA and the RNA work, and how you have to be careful because you can contaminate the room with DNA, and you can't ever get it out. And so I've been learning lots of the—I don't actually know all the names of them—but I have been learning a lot of molecular biology techniques. (BURST student)*

Students also noted increased appreciation of the relevance of their learning from coursework to their research project. Conversely, their enhanced understanding of their discipline from their research experience transferred to their coursework.

> *My lab is [in] integrative physiology, we have to relate a lot of things that aren't necessarily specific to my field, to my research. Just to understand it in the body as a whole. And so then when I go to my classes, and learn the same things, it's really just reinforcing that information. (BURST student)*

In conclusion, students described a progression of intellectual growth as they advance in the lab. Novice students noted gains in data collection techniques and critical thinking skills as they confront setbacks and learn to trouble-shoot experiments. More rarely, some experienced students reported gains in higher-order scientific thinking skills, such as identifying a research question, or developing and modifying an experimental design. Gains in higher-order scientific thinking skills are uncommon for undergraduate researchers (Hunter et al., 2007; Kardash, 2000), and in this study were only realized by advanced students. Students' reports of lack of gains in "thinking and working like a scientist" often referenced a lack of growth in advanced analytic or epistemological thinking skills. Nonetheless, intellectual gains were the most important gain for both novice and experienced students, suggesting that intellectual growth and development is essential for all UR students, regardless of their prior experience.

Personal/Professional Gains

In the category of "personal/professional gains," students noted increased confidence in their ability to do research and to make a contribution to scientific knowledge. They also discussed the benefits of establishing a collegial relationship with an advisor and peers. Though vital to students' development as future scientists, this category was less prominent in students' reports of gains. Personal/professional gains were the fourth (out of six) most commonly mentioned category of gains, comprising 14% of all positive gains statements. Although students made fewer positive comments in this category compared to other categories, they also made very few negative/mixed statements—there were only four negative/mixed comments in this category. Because mentoring was an explicit focus of this research and was probed deeply in the interviews, many comments about mentoring and lab interactions were coded and analyzed within a separate category. Therefore, it is possible that this category may be undercounted because of explicit decisions made in the design of the interview protocol and analysis of interview transcripts.

Collegial relationship with peers and scientists

As noted, students' interactions with their advisors were analyzed separately and will be discussed in greater detail in a later section. Nevertheless, the opportunity to establish a collegial, working relationship with faculty and graduate students was an important benefit to students. With the exception of two students with ineffective advisors, almost all BSI students discussed the benefits of their relationship with their advisors and other senior scientists in their labs.

Both BURST and UROP students also discussed the benefits of establishing collegial relationships with peers and other personnel in their lab group. Students in our four-college study often worked one-on-one with faculty and did not always have the opportunity to work closely with a team of researchers, but BSI students discussed the benefits of developing collaborative relationships with their research team more often. Both BURST and UROP students reported equivalent gains in collaboration and teamwork (56% of BURST students and 60% of UROP students reported gains in teamwork and peer collegiality).

In contrast with what is often the student experience in a research-extensive university, the development of collegial relationships was particularly important for students. Students did not often have the opportunity to develop relationships with faculty and graduate students during their college careers, and the research group offered a smaller environment in which to form close, working relationships with scientists.

> *So the major benefit [of research] is having a smaller group of people that is very supportive, very knowledgeable, and that can be of good mentoring use. Because I went to a very small high school, and then coming to CU it was huge! And I was like, "None of the faculty care about their students!" And I didn't really feel like I had a mentor at all. And [my P.I.] is a great mentor. I can ask her for advice on Ph.D. programs. And the grad students are really helpful about all that also. And basically that's the biggest thing that I've gotten. (UROP student)*

Increases in confidence

Students also discussed increases in confidence as an integral aspect of their personal and professional growth. Students gained confidence and began to develop an identity as a scientist when they felt that they had made a contribution to their field. Equivalent proportions of BURST and UROP students noted that they gained confidence from their research experience; however, the nature of their comments differed. BURST students were more likely to mention gains in confidence in general, while UROP students were more likely to discuss specific gains in confidence in their ability to do research or be a researcher.

BURST students described becoming more comfortable in the lab and gaining confidence from their interactions with scientists.

> *I felt pretty uncomfortable when I started, because it was a really new situation for me, and it was outside of what I had done before. And so now I feel a lot more comfortable approaching people who have Ph.D.s, and masters' [degrees], and asking them about their work, 'cause I've worked with them now. (BURST student)*

While BURST students were beginning to feel comfortable being *around* scientists, UROP students were beginning to see *themselves* as scientists. UROP students noted increased confidence in their ability to do research and that they could "be" a scientist.

> *It definitely opened my eyes to how the whole field works. I know when you're an undergraduate, or even younger than that, high school, and you're not involved in this process, it seems kind of like an other-worldly thing— you read about the word "scientist." And, so it allows you to feel more comfortable with the [research] process, and more confident in how it all works. And it makes you able to be like, "I could actually maybe do this, if I find I want to, and open doors." (UROP student)*

> *I've definitely gained confidence in my ability to both "do" and "be" a scientist. I mean, I haven't 100% done my own thing because a lot of this was under the supervision and guidance of who I've been working with, but I feel like when the time comes I'll be able to do that. I'm sure, in the future, I'll be able to design experiments on my own and that would be no problem. (UROP student)*

UROP students also discussed the benefits of contributing to science. Students found great reward in the process of discovery and generating new knowledge. BURST students, for the most part, had not advanced enough in their project to acquire publishable results; but some UROP students with multiple years of lab experience had generated results that could advance knowledge in the field.

> *I actually have some preliminary data that is the first to ever show this particular thing. So I think that was really rewarding, to be able to go up to [the P.I.'s] office and say, "I think I might be the first person in the world to have found out something." (UROP student)*

In sum, personal and professional gains were not a predominant category of gains for BSI students. Students noted increased confidence in their ability to conduct research and "be" a scientist, and described the benefits of establishing collegial relationships with advisors and peers in their lab groups. There were few programmatic differences in outcomes within this category; however, UROP students were more likely to feel that they had made a contribution to the field. More experienced research students also described their development of an identity as a scientist as they gained confidence that they can do scientific research.

Becoming a Scientist

Through participation in research, students began to adopt the temperament, behaviors and attitudes necessary to become a scientist. Students demonstrated gains in the ability to think and work independently and to take "ownership" for a project. Students also increased their understanding of professional practice and began to develop patience and perseverance in the face of setbacks and failures in the lab. The category "becoming a scientist" was the second largest among students' gains comments, comprising 21% of positive comments within all of the gains categories. Students made few negative/mixed comments, which only accounted for 6% of comments within the "becoming a scientist" category.

Becoming a scientist: Developing the temperament of a scientist

Both BURST and UROP students discussed developing temperamental characteristics, such as patience and perseverance, which would help them in a scientific career. Students learned to persevere when their experiments did not go as planned, and to be careful and meticulous about laboratory procedures.

> *I'm not a very patient person, and so I think that it taught me to be patient. And to realize that it's better to do something accurately, if you have to do it a little bit slower, than to rush through everything, and screw it up. (BURST student)*

Students also learned about the nature of scientific research work; that is slow, lengthy, and rife with setbacks and failures. Yet novice students did not always generalize their own experiences to the research process in general. For example, a BURST student described her particular project as "finicky" (e.g. prone to errors or failure), indicating that she ascribed the fallible nature of the research process to her own project, but did not yet have a sophisticated enough understanding to generalize her experiences to the scientific research process.[3]

As students gained experience in the lab, they became more comfortable with the time that it took to do careful research.

> *I think it's definitely easier for me now that I know the timeline that research entails. At the beginning it was kind of frustrating because I didn't really understand that and I wanted*

[3] The corresponding quote is not included in report because it contains identifying information.

immediate feedback. But now that I understand how it works, it's a lot easier. (UROP student)

Becoming a scientist: Gains in independence

Within the "becoming a scientist" category, the majority of BSI students noted gains in the ability to think and work independently. However, slightly more UROP students mentioned gains in independence than BURST students (87% of UROP students and 61% of BURST students noted gains in independence). Their level of independence also differed: BURST students tended to discuss learning laboratory techniques from their advisors and then gaining independence to implement them without supervision.

> *And it's kind of nice, when I learn something new I work directly with [my advisor], and then at some point he allows me to kind of have the autonomy to do things on my own, and then follow up with him on it. So it's kind of nice that they're trusting me to do work on my own. (BURST student)*

Advanced students, in contrast, discussed gains in independence not only in terms of conducting laboratory procedures, but also in thinking through problems or findings.

> *When I first started, earlier this year, I would say I was a lot more involved with my postdoc, he'd be showing me how to do things, explaining to me how to do this, or how to do that. And then just as the year went on, I was expected to figure it out on my own. Or he would explain something to me, and then the first time he would tell me, I would be like, "Okay, I'll just take your word for it." And then over the next few days, I'd somehow figure out why that was right, or why that's important. So I was expected to figure out a lot of things on my own. (UROP student)*

Advanced students also demonstrated independent thinking in determining the next steps of their experiment.

> *I'm a pretty independent person, usually I try to figure things out on my own—but I've definitely been thrown out into the field before and have [my advisor] expect me to know what to do. Or there's days where I come into work and set up the schedule and I'll just have to find the next step on my project and decide which way to go and then sort of check back with my P.I. .... I've definitely had to become more independent. (UROP student)*

> *It took a while because, I think freshman/sophomore year I was like, "Okay, that kinda makes sense," and then junior/senior year is when I started thinking independently of other people. (UROP student)*

While BURST students often demonstrated the ability to *work* independently without close supervision from their advisor, UROP students also demonstrated gains in the ability to *think* independently about their projects.

Becoming a Scientist: Gains in ownership of a project

The opportunity to develop a sense of ownership over a project is a powerful outcome for some UR students and is a critical element in generating intellectual, personal and professional growth (Thiry et al., 2009). UROP students more often felt a sense of ownership and responsibility for their project than did BURST students (73% of UROP students and 11% of BURST students described a feeling of ownership over their project). A UROP student described the transition from working on an advisor's project to working on a project that felt like his own.

> *Last time it was more of me working on his project, but this time this is more my own project, and so I have a little bit more independence. (UROP student)*

UROP students who had input into the design of their experiment felt that the opportunity to think and work independently on their own project was highly rewarding.

> *The most rewarding thing is when something works and something that you designed turns out well, and you get products from something that you designed with your own ideas in mind. I think that was best. (UROP student)*

A lack of gains in independence

The majority of negative comments in the "becoming a scientist" category referenced a lack of independence or a lack of ownership over a project. Most of these comments came from BURST students who did not have the opportunity to work autonomously. Some students from both programs did not feel ownership of a project because their work was part of their advisor's project; however, some students who worked on another scientist's project still felt a sense of ownership over their piece of it. Thus a sense of ownership did not necessarily stem from whether the project was solely that of the student, but emanated more from whether students felt that they had some autonomy and control in making decisions about the work.

A few students also recounted that they were supervised closely and not allowed to work independently in the lab. Such lack of opportunity to engage in independent work hindered students' intellectual and professional gains, while the opportunity to work autonomously and make mistakes helped students learn to solve problems and think creatively.

> *The only complaint I had is that, I feel like my mentor, I understand a lot of what's going on, but I don't feel like there's much of a chance for me to... She doesn't just be like, "Okay, here's what you're doing, I'm leaving." I feel like sometimes in order for me to understand things better, or to really make sure I know what I'm doing, I need to be given the chance to do things on my own…. And a lot of times she'll help me with the stuff, and put it together, and then I'll do it. But she's still there supervising…. And I feel like I really haven't had the opportunity to do things on my own. I've had a few times, I've screwed up, and she's like, "Oh I can't let you do this by yourself again." (BURST student, negative comment)*

In sum, both BURST and UROP students began to display characteristics of a successful scientific researcher; however, the nature of their gains varied. Novice researchers—primarily BURST students—were more likely to note that they gained patience and perseverance and began to take greater care with laboratory procedures, while more experienced students discussed gains in independence, initiative and ownership. A few students did not have the opportunity to work independently in the lab, reducing their opportunity to learn to solve problems and learn from mistakes.

Becoming a scientist: Understanding professional practice

Another sub-category within "becoming a scientist" reflects gains in understanding the professional practice of scientists. UROP and BURST students mentioned this gain in similar numbers, though it was not a common gain among either group. Nevertheless, the opportunity to work closely with and observe faculty and graduate students offered students valuable insights into the lives and daily work of scientists. One student noted that, although his parents are faculty members, he did not gain a real appreciation of the professional practice of faculty until his research experience.

> *I've also just gotten a greater appreciation for like the whole process, 'cause both my parents are professors, and my mom's a biochemist. And so she used to tell me about working in the lab, and how hard it is to get papers published, and all of that. I had no real idea of what that was. And I think that after working with the BURST program, I have a better understanding of what you have to go through to get papers published, and how good your research has to be. And how your protocols have to be, how good and everything, before you can publish it, and show it to the rest of the world. (BURST student)*

Another student's comment shows how the quality of a research experience can impact students' understanding of professional practice and scientific careers, by contrasting experiences that provided different levels of appreciation of the various roles and career stages within a research team. His first research experience—as a volunteer—involved low-level "grunt" work that was not challenging, while his second experience encompassed hands-on participation in an authentic research project.

> *I got a much better grasp and overview of what it's like to work in a research lab, or be a grad student or postdoc and all that good stuff. Because I didn't even know the difference between a grad student and a postdoc when I was in my other lab. I just went there once a week and I did the stuff they told me to do once a week and then I forgot most of it by the time next week came. (UROP student)*

A lack of gains in understanding professional practice

A small fraction of students did not have the opportunity to observe professional practice during their research experience. Negative comments in this sub-category came primarily from students who had little interaction with their P.I.s and could not observe the life of a faculty member. A few students also did not work closely with graduate students and thus did not learn about the life of a graduate student. The comment below is from a student who learned very little about graduate school during his research experience.

> *I still don't necessarily know [about graduate school]. I know you have to work in a lab, and you have to be taking classes, but that's pretty much all I know. I've not really looked into it much more than that. (UROP student)*

In sum, in the category of "becoming a scientist," students described the development of temperamental characteristics, such as patience, independence, and initiative, which are necessary to become a successful researcher. BURST students often noted gains in the ability to *work* independently, while UROP students also noted growth in their ability to *think* independently about their project. UROP students also reported a greater sense of ownership over their projects. A few students did not have the opportunity to work independently in the lab, which hindered their ability to learn problem-solving skills or to learn from mistakes and setbacks.

Summary of intellectual, personal and gains

The above three categories—"thinking and working like a scientist", "personal/professional gains", and "becoming a scientist"—demonstrate the intellectual and personal growth of students as they advance from novice to more experienced undergraduate researchers. Novice researchers developed basic cognitive skills, such as mastering data collection techniques or gaining an understanding of the process of scientific research. Novice researchers also made general gains in confidence as they became more comfortable with interacting with scientists and working in a scientific laboratory. Entry-level students developed patience in the face of setbacks, learning that they must take care with their laboratory procedures. In addition, some advanced researchers gained higher-order scientific thinking skills, such as the ability to interpret data, design an experiment or generate a research question. Advanced students also gained confidence in their abilities as scientific researchers and that they could become scientists. Experienced researchers began to display independence by taking responsibility and ownership over a research project. We now discuss other gains that are distinct from these personal and intellectual gains.

Skills

One of the most common benefits mentioned by BSI UR students were gains in skills. Skills was the third most frequent gains category, comprising 19% of all students' positive gains comments. Students mentioned gains in written and communication skills, mastery of new research and laboratory techniques, and gains in organization and time management. Students also mentioned improved reading comprehension skills, particularly for scientific journal articles, information retrieval skills, and abilities to work collaboratively with peers, faculty, and other scientists. Still, thirteen percent of students' comments within the "skills" category were negative/mixed statements, primarily from BURST students who had not had an opportunity to present their work and thus gain scientific communication skills.

Skills: Gain in laboratory techniques, reading comprehension and information retrieval

Many students mentioned gains in laboratory skills and the ability to take measurements and calibrate instruments. More BURST students noted gains in laboratory skills than UROP students (78% of BURST students and 47% of UROP students). Gaining proficiency in basic laboratory techniques is a necessary first step in the development of scientific expertise, and thus may be more important to novice students. In one of the only gender differences detected in this study, the development of procedural skills was a particularly significant outcome for women, who noted gains in confidence from their mastery of laboratory techniques. Participation in research generated increases of confidence for women that coursework alone had not.

> *Before when I was taking the organic chemistry lab, and other chemistry labs, I wasn't comfortable using that equipment. But since I have been using that stuff for a longer time [in research], I feel more comfortable. And then I don't feel shy about using the stuff. (female BURST student)*

> *I've learned a lot of techniques, and I've used a lot of equipment that I wouldn't otherwise use in probably just a regular chemistry lab, or anything else. It's been really cool, so I feel like I have a lot stronger background, and I'm not really intimidated about lab anymore. (female UROP student)*

Many students also noted gains in reading comprehension skills from reading journal articles to gain background knowledge about their projects. More UROP students reported developing scientific reading skills than BURST students (93% of UROP students and 61% of BURST students reported gains in this area). A BURST student described how discussions with her advisor helped to improve her ability to comprehend difficult journal articles.

> *During the first semester on my research, when [my advisor] gave me a paper, I would be like, "I don't know anything, it doesn't make sense at all." But he would be like, "Okay, I can explain it to you." And he used to explain all the stuff in an easy— in a language that I would get. And during the second semester, when he gives me a paper to read, I don't find it that difficult. I still do have difficulty understanding the material, but it's not as difficult as the previous semester. (BURST student)*

On the whole, UROP students demonstrated a greater comfort with journal articles than BURST students.

> *I've had to do a lot of paper reading to find out some information, background, to see if other people have been getting the same sort of results that I have. So it's sort of taught me to skim my way through a research paper. And I just feel more comfortable navigating in that sort of research environment. I feel more comfortable with the jargon and understanding the figures and things like that. (UROP student)*

Because many UROP students had already developed the ability to understand journal articles, they used the literature instead to gain ideas or to identify areas for further research.

> *There's a couple different papers, well* only*, a couple phylogenies came out in the past two years for these species. So I read those to get an idea of the divergent signs between the species, but most of the papers that I read have been dealing with experimental embryology and developmental biology and things, to decide which genes we're gonna look at in these species. (UROP student)*

Most students were given research articles by their advisors, although some students also searched the literature on their own. More UROP students reported gains in information retrieval skills (61% of UROP students and 28% of BURST students reported gains in this area). These students learned to find articles and navigate academic databases independently.

> *I did read a fair amount of research literature… I pretty much went online, And so once I got that figured out [the VPN], it was very helpful, so I pretty much just did a lot of it on my own. (UROP student)*

In sum, students reported gains in a variety of skills, including laboratory techniques and instrumentation, scientific reading comprehension, and information retrieval. Students gained the ability to understand scientific terminology and methodology from reading scholarly articles and learned to navigate scientific databases as they located articles on their own. Novice students discussed gains in laboratory skills more often than experienced students, while experienced students noted greater gains in reading comprehension and information retrieval. Few BURST students mentioned finding scholarly articles on their own, while the majority of UROP students noted that they had utilized library databases to search the literature.

Skills: Scientific communication skills

Students reported gains in oral communication skills, particularly learning how to present in a professional environment and to defend an oral argument. Students in our four-college study also reported strong gains in communication skills, particularly presentation skills (Hunter et al., 2007). In the present study, there was wide variation by program regarding gains in presentation skills. Only two BURST students discussed gains in presentation skills, while two-thirds of UROP students discussed growth in their confidence and ability to present scholarly material.[4] UROP students, for the most part, reported gains in poster preparation, argumentation, and increased confidence in scholarly presentation. The poster requirement for the UROP program helped to augment students' presentation skills, although some UROP students also presented at research group meetings, one student presented at a professional conference, and one student discussed the oral defense of her honors thesis. BURST students, on the other hand, had limited opportunities to present—either through the program or within their lab group—and thus reported little to no gains in oral presentation or argumentation.

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[4] UROP students who did not discuss gains in presentation skills had not yet had the opportunity to present their poster at the time of the interview. Therefore, they discussed *anticipated* gains in presentation, although those gains had not yet been realized.

One of the two BURST students who mentioned gains in oral presentation had presented to her lab group's journal club, offering her the opportunity to receive constructive critique of her presentation and improve her presentation skills. This growth also transferred to the classroom.

> *I think it's taught me a lot about how to do that. And [the P.I.], as well as asking scientific questions, will kind of critique us on our style of presenting, and our slides. And I've gotten rid of a lot of nervous habits with presenting, and things. So I feel that for other classes, my presentations have improved because of it as well. (BURST student)*

UROP students had more opportunities to present findings during their research experience. One student reported that he gave a poster at a professional conference, which also provided the opportunity to learn about current research in the field and to network with scientists.

> *I was actually first-author on a poster—an abstract at a conference last year. So I got to go and actually tell people about our research, which is pretty daunting. It was great. Our field isn't super-widely studied, so I got some blank stares at the conference, just because they weren't familiar with what we were doing. But overall, it was an amazing experience, to be immersed in that whole process, and decide what talks I wanted to go to that day, and interact with people whose names I've seen on these papers I've been reading, and things like that. (UROP student)*

The majority of UROP students reported gains in presentation skills from preparing and presenting their posters. Students noted that presenting a poster extended their scientific communication skills in ways that everyday interaction in the lab could not.

> *Anybody, well I guess not anybody, but anyone can just go in and collect data, and analyze it and make sense of it. But it's pretty difficult to try and present it to other people. So it, that was also a very good, opportunity I had to try and present it to other people that obviously have some sort of science background, but may not have any idea what I'm doing. So it was a good experience. (UROP student)*

Most BURST students did not have the opportunity to communicate the results of their research to an audience of experts or peers. BURST students mentioned that they had to write a paper at the end of their research experience, but had no presentation requirements. Most students also did not present within their lab groups.

> *We have to write a paper for BURST, to turn in. But as far as for my lab, I don't think there will really be anything. (BURST student, negative observation)*

Because of the differences in program elements, more UROP students mentioned gains in scientific writing skills (17% of BURST students and 60% of UROP students noted gains). Half of UROP students reported that writing the UROP proposal strengthened their writing skills, while three UROP students discussed co-authoring articles in peer-reviewed journals, and one mentioned publication in an honors journal. Such experiences helped students to learn about the peer review process.

> *The professor did ask me to help co-author a review paper, so I've been able to do that kind of writing. We've submitted it for review just a couple days ago. So we're hoping for good news. They haven't formally accepted it, but this is the second time—the first time we sent it in, they sent it back to us and told us what was wrong with it basically. And then this time we tried to fix everything and make sure we addressed all their comments. (UROP student)*

While such special writing opportunities were clearly influential, most BSI students who discussed writing gains received those gains from writing the UROP proposal. Students were often unfamiliar with proposal writing and the UROP proposal helped them to learn the structure and requirements of academic proposals. Students also viewed proposal writing as a skill that would transfer to their future scientific careers.

> *It was helpful 'cause I learned how to—[the]* only *HHMI grant proposal is the first one I've written, and, I kind of got a feel for that. It helped me with my scientific writing a lot more, 'cause I hadn't worked on that before, at all. (UROP student)*

> *Just writing a proposal, it wasn't exactly the same type of proposal that you would write if you were applying for a grant, if you were a postdoc or a graduate student or whatever. But it's definitely the same kind of ideas, and so I think that's a great practice run for the real deal. (UROP student)*

Experienced research students reported the greatest gains in communication skills. UROP students more often had opportunities to disseminate their results in refereed papers or presentations, although this was still rare, as we found in the four-college study (Hunter et al., 2007). UROP students also gained greater oral presentation and scientific writing skills because of their program's requirements. The gains thus demonstrate the value-added of the UROP program: most gains in scientific communication skills emanated from participation in the program, and not from a research experience alone. Consequently, BURST students' gains could likely also be augmented with more rigorous communications requirements, particularly the opportunity to present in a formal setting. Providing BURST students with the option to participate in the UROP poster session is a promising start, although BSI staff could also consider mandatory participation for BURST students. Other communication tasks might also be required to help students prepare for the poster presentation, such as writing an abstract, describing one's research for a job or scholarship application, or a less formal oral presentation to peers not in the same group.

Enhanced Career/Graduate School Preparation

Participation in research helped students to feel prepared for graduate school and future scientific careers. These experiences enhanced students' résumés, provided opportunities to network with faculty and other professionals, and exposed them to new experiences. While they reported gains, students did not perceive that enhanced readiness for careers or graduate school was a highly important outcome from their research experience; this was the least common category of gains comments, comprising only 7% of all comments. There were no negative/mixed comments in this category.

There were no major differences between BURST and UROP students in this category. Students in both programs discussed the benefits of having a "real-world" experience that would provide valuable preparation for a future career.

> *I'm glad that I've had a chance to get some real life experience and... I hope this experience will help me later sometime and I'm pretty confident that it will…. (BURST student)*

Both BURST and UROP students felt that participation in research enhanced their résumés and graduate or medical school applications. Students also believed that research prepared them for the tasks and responsibilities that they would encounter in graduate school.

> *I don't think you can really put a price on [the research experience] per se. Because in order to go into [graduate school], it seems like every year it gets more competitive, as far as what they're looking for. Ten years ago you didn't need any research experience, and now, if you don't have research experience, it's very tough for you to get in. So it's totally needed, if you want to go to a graduate program, or med school, or anything like that. Definitely it's very helpful. Plus, I mean, you go into those programs, you're gonna be doing that type of stuff, or you have to be familiar with it, because you'll come across it in some kind of way. (BURST student)*

UROP students discussed the benefits of receiving career and graduate school advice. UROP students were closer to graduation than BURST students and may have begun to think about life after college. Students found it particularly helpful to observe graduate students and ask them questions about their studies.

> *Just weighing out, whether I really wanna go [to graduate school]. And at the same time, it's nice to have access to asking [the graduate students] for advice about what to do in terms of grad school and, whether waiting a year is okay… and just, how did they pick their school, their field, even their lab right now. And so that's been helpful because then it allows me to start thinking about it. (UROP student)*

UROP students also sought advice from P.I.s about graduate school or medical school decisions.

> *I went and talked to [the P.I.] about a month ago. I was trying to decide what I wanted to do grad school/med school-wise and so we sat down and had a nice long conversation about grad school and med school and the application process and what I'm interested in. (UROP student)*

Gains in "enhanced career and graduate school preparation" were not a significant outcome for BURST or UROP students. This is in line with students' motivations to pursue research; they primarily noted intrinsic reasons, such as interest in the topic, rather than external reasons, such as career preparation or enhancement of graduate school applications. The differences in students' comments indicate that the opportunity to gain "real-world" experience was beneficial for many BSI students, while UROP students also sought advice about graduate school and future careers.

Clarification of Career Aspirations and Interests

Like “enhanced career and graduate school preparation,” the “clarification of career aspirations and interests” was not an important outcome for most students. This was the next-to-last category of gains, comprising only 12% of all positive gains statements. Many students were still uncertain about their long-term educational goals and career paths, and were not concerned about clarifying their future paths. Moreover, 19% of comments in this category were negative/mixed observations—the largest category of negative/mixed comments. In the four-college study, poor research experiences turned some students off from science (Thiry et al., 2009). In this study, negative comments were less an indictment of the research experience itself, but rather reflected students’ uncertainty over their future paths. For some undecided students, the research experience had not helped to clarify future educational or career goals.

The career and educational goals of BSI students were:

- BURST students were more interested in medical school or health careers (nine BURST students and one UROP student)
- UROP students were more interested in graduate school and research careers than BURST students (six UROP and two BURST students had definite plans to attend graduate school, eight UROP and eight BURST students were considering graduate school).

Although UROP students were more interested in research careers than BURST students, this did not necessarily result solely from the research experience. BURST and UROP students had different interests prior to the research experience; more BURST students were initially interested in medical careers, and more UROP students were interested in pursuing graduate school. However, some students did state that research had influenced their educational and career choices. We will now discuss in more depth students’ short-term plans of whether to remain in research, and the influence of the research experience on students’ long-term career and educational goals.

Immediate plans for research

The majority of students (both BURST and UROP) planned to continue with research: 61% of BURST students (n=11) and 60% of UROP students (n=9) had definite plans to continue UR in the upcoming academic year. Two BURST students and no UROP students had definite plans not to continue with research; the rest were undecided.

The primary reasons that students cited for desiring to continue with research included enjoying the sense of community in the lab group, receiving encouragement from the P.I. or advisor, having a feeling of ownership over the project, anticipating the opportunity to contribute to scientific knowledge, and wanting to gain more “real-world” experience. The two students who chose not to continue with research cited financial concerns, busy schedules, and lack of interest in the research project.

Many students mentioned that collegial relationships in the lab and interest in the topic were factors that influenced their continuation in research.

> *I really like the people I work with, I know that lab very well as far as where things are, and I'm really interested in neuro-degenerative diseases. So....[my project] would be a good one to help me in that direction. (UROP student)*

Other students felt a sense of ownership over their projects and wanted to continue their investigations. The open-ended nature of scientific investigation had piqued their curiosity; it was hard to let go of a project when there was still so much to learn.

> *It's ongoing, really. I wrote up a proposal for HHMI that was neat and packaged and, everything didn't go according to plan, and so there's additional avenues of research that have opened up and there are some avenues of research that have closed down. And so, I'd be interested in pursuing those avenues further. It's ongoing. I mean, we're never going to figure out everything about everything. (UROP student)*

Two students had decided not to continue with research. Besides financial or time concerns, both of these students mentioned lack of interest in their projects.

> *It's not the challenges of research, it's more just that I'm not interested in it as much as I originally thought I was. (BURST student)*

Students who chose to continue with research are intellectually and socially integrated into the lab. Tinto's (1975) theory of student persistence posits that students are retained in higher education through academic and social integration into the university: they are engaged with their academic work, care about their academic performance, and have developed networks of social support. Our findings validate Tinto's theory and broaden it to persistence in the research experience. Students who were intellectually engaged with their projects, and who had supportive, collegial relationships with their lab groups, were more likely to persist in research. These findings highlight the importance of intellectual and social integration of undergraduate students into the research group. Interest, intellectual engagement, and collegial relationships were key factors in students' decisions of whether to continue with research.

Educational plans

Many students, including graduating seniors, were still uncertain about their future educational plans. BURST students were more interested in attending medical school or pursuing health careers (50% of BURST students and 7% of UROP students expressed interest in medical careers). Most of these students entered their research experience intending a career in medicine; participation in research had not changed their commitment to this goal. UROP students were more interested in graduate school (40% of UROP students and 11% of BURST students expressed a strong commitment to pursuing a Ph.D.). In addition, 53% of UROP students and

44% of BURST students were considering graduate school. Unlike their peers who were interested in medical careers, students interested in graduate school tended to be less firmly committed to this plan. Many had participated in research because they wanted to clarify whether graduate school or a research career was the right path for them. Some of these students (40% of UROP and 11% of BURST) became more firmly committed to the goal of graduate school because of their research experience, while others were still uncertain about their future plans.

Career plans

Students were more uncertain about their career goals than they were about their educational goals. In fact, the vast majority of students expressed so much uncertainty about their future plans and often cited multiple career possibilities that it was near impossible to make an accurate count of students' career plans. Nonetheless, five students (all UROP) planned to enter a transitional job in a research lab after graduation and then apply to graduate school. Some students (n=10, nine BURST and one UROP) were committed to a career in medicine or health care. One student expressed interest in a research career in industry and four students (two BURST and two UROP) sought to enter the professoriate. However, most students were uncertain about their plans; even some students who were leaning toward or committed to a certain career were also considering other possibilities.

Influence of research on career and educational paths

Students cited the following ways in which research had influenced their future plans:

- Research clarified that student does not want research career, (10 BURST and 0 UROP)
- Research has not changed pre-existing plans, (6 BURST and 4 UROP)
- Student changed career plans to research, (4 BURST and 3 UROP)
- Student changed career plans away from research, (3 BURST and 0 UROP)
- Research clarified that medical school is the right path, (4 BURST and 0 UROP)
- Research clarified that graduate school is the right path (0 BURST and 4 UROP)
- Student now considering graduate school because of research, (2 BURST and 6 UROP)

Participation in research helped many students to clarify or confirm whether a research career was the right path for them. However, participation in research rarely *introduced* the idea of graduate school or a research career; most students were considering these paths as viable options when they began the research experience. Indeed, some students reported that they were motivated to participate in research to clarify their career and educational choices. So it is not surprising that some students clarified that research was not a good career choice for them. In fact, ten students (all BURST students) discovered that "research is not for me."

> *What I was thinking about doing when I first came to school, was trying to follow up my undergraduate education with working with genetics, and researching genetics. And since working in the lab, I've gotten to experience the stress, and a lot of the bureaucracy that is involved with research. I just don't feel like—it wouldn't be a good match for me. Despite how much I've enjoyed it as an undergraduate, I think doing it on the*

professional level for my career, would be not something that I would be interested in. (BURST student)

Some students also discovered that they do not have the patience or temperament to be a scientific researcher. These students found the research process to be too slow and ambiguous.

Definitely one of the things that research has shown me is that I don't want to do this. Because you can work for years and years and years and never find what you're looking for. And I just know that I couldn't do that. I need results... so I know that it's definitely showed me that I don't want to do research forever. (BURST student)

For others, participation in research helped to clarify that graduate school was the right path for them. Four students (all UROP) reported that research had helped to confirm that graduate school was the right path for them, while eight students (two BURST and six UROP) reported that research had increased their likelihood of attending graduate school. Some students, typically those already committed to a medical career, reported that research clarified that medical school was the right path for them. Moreover, four students (all BURST) reported that although they had considered research as an option, they decided after working in the lab that a medical career would be a better path.

Mostly I was thinking about going into research, but since having this experience, I've decided not to. Not because I've had a bad experience with the lab, or with the BURST Program, just because I don't feel that research is for me. Since working in the lab, I've decided that I would like to attend medical school, and that's been, a big change for me, and I'm really excited for it. (BURST student)

Based on their research experience, some discovered that they enjoyed research and that graduate school would be a good choice for them.

It really helped me decide which direction I wanted to go after I graduated, so now I want to do the same kind of stuff in another lab. It doesn't even matter what it is, as long as it's research-related. I don't know about my whole life, but for the near future at least, I just want to go to grad school. I want to get a Ph.D. (UROP student)

Participation in research, particularly in a lab with graduate students, allowed students to learn more about the life of a graduate student and the process of selecting and applying to a graduate school.

And in terms of career paths, it's really nice being in the lab, because all the graduate students are— essentially that's what I wanna do, is go into grad school and do research. But I just didn't really know HOW, I guess… the path and thought process of these students. So it's nice to get to know them and then kinda see how they basically live as a grad student. (UROP student)

In sum, participation in research had a modest impact on students' career and educational paths. As in the four-college study, many students simply confirmed prior interests or clarified competing interests. Participation in research also helped to educate some students about career options. The research experience seemed to have a larger impact on UROP students than BURST students. 40% of UROP students (n=6) and 22% of BURST students (n=4) reported that they changed their career plans and are now considering graduate school because of research; however, few of these students had immediate plans to attend graduate school. Most were planning to take a transitional job in research and then apply to graduate school. Moreover, 17% of BURST students (n=3) had been considering attending graduate school, yet changed their minds because of their research experience. This latter group did not change their plans due to a poor research experience; they simply discovered that the life and work of a scientific researcher was not a good fit for them.

Because so many students were still uncertain about their educational and career goals, it is too early to evaluate the impact of students' participation in research on their long-term educational and career paths. We faced the same issue in our longitudinal analysis of student outcomes in the four-college study: several years after their research experience, many students were still in transitional jobs with uncertain long-term plans. We can tentatively conclude that participation in research had a modest impact on students' short-term plans, in the sense that it helped some students to clarify whether graduate school or medical school was the right path for them. A few students also changed their career plans to research; however, we cannot determine the long-term impacts of their participation in research at this time.

Authenticity of the research experience

In light of our previous findings from evaluation of BSI UR programs (Coates et al., 2005), coupled with findings from the comparison sample in our four-college study (Thiry et al., 2009), we surmised that students' outcomes from the research experience were integrally linked to the authenticity of their research work. For instance, in our earlier evaluation of BSI's UR programs, some advisors asserted that students simply served as "extra hands" in the lab, and a small group of students reported negative outcomes from their research experience. Likewise, students in the comparison sample in our four-college study had highly variable research experiences. Many of the students who engaged in off-campus research or a senior thesis project had a highly beneficial experience; but a few students reported poor-quality experiences that did not generate the same level of gains as their peers who conducted summer research on campus (Thiry et al., 2009). Findings from these two studies suggest that the authenticity of students' research work and the quality of advising they receive are key factors in generating student gains. We further tested this hypothesis in the present study by probing issues related to the authenticity of students' activities and responsibilities in the lab, and the quality of the advising they received. We will now discuss in detail the findings regarding the authenticity of students' research work, followed by an extended discussion of advising.

In interviews, we probed for specific markers of participation in authentic research—as opposed to "busy work" or bottle-washing. Such markers include participation in research that can lead to publishable results; student involvement in higher-order scientific tasks, such as data analysis or experimental design; the extent of student autonomy over experiments and work space; and high levels of engagement (e.g. working extra hours, etc.). In essence, we were interested in the nature of students' day-to-day activities and tasks in the lab, and their level of intellectual engagement with their work. All but two students participated in authentic data collection or analysis tasks in the lab; BSI students mentioned 40 data collection techniques and 14 analysis methods in which they engaged. The other two students—both from the BURST program—were involved in project set-up for most of the year and had little opportunity to engage in more meaningful research activities. A few students—all BURST—did not have the opportunity to advance beyond routine data collection activities.

Overall, UROP students demonstrated more of the key markers of authentic practice than did BURST students. BURST students' comments often reflected their novice status in the lab. UROP students were more likely to report that they had their own work space; seven UROP students and one BURST student had their own desk or work space in the lab. BURST students, for the most part, reported that they shared work space with other undergraduates or other members of the lab group.

> *The lab is small, but we got a new room where all of the computers have been moved, and now I do have a desk, and I have a computer, and I kind of share bench space with everyone. (UROP student)*

UROP students were also likely to work extra hours on their project, including evenings or weekends, because they held greater responsibility for their experiments. For example, 11 UROP students and one BURST students reported that they regularly worked extra hours, beyond their approximate ten hour per week commitment. These UROP students typically spent 15-20 hours a week in the lab to prep for or conduct their own experiments.

> *On the easy weeks, it was probably... I dunno, five hours, just doing these weekly tasks that everybody has, like making sure the pH chemicals are fresh, or something like that. But then when I was doing the actual research, it could've been up to 30 hours a week. (UROP student)*

> *Since I started a long time ago, I put a lot more time into it. Right now, I have class Tuesday and Thursday, so I go in on Monday/Wednesday/Fridays. And on average I probably go from about, we've been starting at 9:00 or 10:00 to maybe 2:00 or 3:00ish, and that's sometimes a lot less, sometimes a lot more. It just depends on the project that's going on, and what we have to do. (UROP student)*

We also investigated the nature of students' actual activities and duties in the lab. As mentioned previously, most students reported engaging in numerous authentic data collection and analysis techniques. However, some students (six BURST students and six UROP students) also discussed more rote tasks, such as project set-up, prep work for experiments, clean-up, ordering equipment, filing invoices, and data entry.

These routine research activities did not lead to a poor research experience in and of themselves; indeed, they are necessary tasks to initiate and maintain research. Such tasks, however, can lead to a lack of gains if students are not also given the chance to engage in more complex work and encouraged to think deeply and creatively. A small fraction of BSI interviewees (four BURST students) engaged in "busy work" tasks but had no chance to engage in higher-level intellectual work. Two spent the year involved with project set-up and did not have the chance to collect data or begin "real" research work. Even menial tasks, such as setting up a project and ordering equipment, can teach students about the research process and methodological decision-making—but these students were not challenged to think deeply about why the project was being organized the way it was, nor invited to participate in decision-making. The following comment is from one of these students and reflects a technician's duties more than a researcher's role.

> *Most of the time I am actually by myself, or with the graduate student. And at this point, mostly because I don't like to 'decap' the animals myself, so I can't really do that research part by myself. But, a lot of times I take care of the other lab duties. Like cleaning up the lab, and taking care of the financial invoices, and the sorts of lab duties, like I fix equipment when they break, and send them out, and talk to the companies, and get things arranged like that. So I'd say most of the time I'm in the lab by myself... (BURST student)*

Because of their more advanced status in the lab, UROP students were more likely to report that they had participated in data analysis and interpretation, or contributed to experimental design. UROP students were more likely to run their own experiments: in fact, 40% of UROP students and 22% of BURST students reported that they were running their own experiments. In the following comment, a UROP student described how he progressed from conducting prep work for other scientists' experiments to conducting his own.

> *So basically this whole last year I was doing much more, I was more involved in the research, actually conducting experiments. As a sophomore I was just setting up the tissue culture, I wasn't actually doing too many of the experiments yet. So I would say, I received a lot more attention this last year, than probably two years ago. (UROP student)*

UROP students were also more likely to have input into the research design of their project or to discuss "next steps" with their advisors. Students learned how to modify or refine an experiment through these discussions. Twelve UROP students and five BURST students noted that they discussed the direction of their research projects or experiments with their advisors—discussions that were necessary in developing independent decision-making.

> *I'm a pretty independent person, usually I try to figure things out on my own…. There's days where I come into work and I'll just have to find the next step on my project and kind of decide which way to go and then sort of check back with my P.I., but I've definitely had to become more independent and organizing this stuff in the process of what I'm doing. (UROP student)*

Other students reported that their level of responsibility and independence varied according to the nature of the experiment. In the following comment, a student mentioned that she is comfortable in basic decision-making, yet still needs guidance for more complex experiments.

> *It depends on how big the next step is, if it's something where I'm doing cell biology, like in my project, I basically know how to do that on my own. I can sit down and say, "All right, I*

want this to happen, what's the time frame?" But for my imaging experiments that are a little bit more large-scale, I for sure sit down with [the P.I.] and think, "What would be the best direction to go next?" (UROP student)

Another key indicator of authentic work is whether students had input into the design of their project or experiment. As might be expected, more UROP students reported that they had collaborated with their advisors to develop the design of their experiment; only one BURST student reported doing so. On the whole, BURST students were still learning lower-level scientific thinking skills and did not yet feel comfortable with higher-order skills such as generating a research question or designing an experiment.

> *I have not been able to do an independent project yet, because in our lab we work in pairs. So our research supervisor gives us an experiment, and lets us know, "You need to do all this stuff," and we plan how to do it. But we are not like, "Okay, this is our project, we want to do this." (BURST student)*

Other BURST students, particularly those in a research lab out of their major, felt that they did not have the conceptual or theoretical background to contribute to project design. They expressed a need for support in generating ideas for research and developing or modifying a research design. As with other intellectual tasks, novice students needed guidance and support from more experienced scientists before they felt comfortable with their own experimental design abilities.

> *I still feel like I need help with coming up, I guess not with my own ideas, but with new proposals, and new experiments that I can partake myself, or be included in. I just don't feel like I have a strong enough background, where I can be like, "Oh, we should search for this gene, or this effect," or something like that.... I kind of just do what I'm told, and I guess it's kind of intimidating to me, because it feels like a new thing to me. I just feel like I don't have enough background to successfully relay what I think about the animals. (BURST student)*

As students gained experience in the lab, they began to feel more comfortable with providing some input into the direction of the project.

> *It's almost like two projects. So he designed the first one and then the second one it was his idea, but I kind of formed what we're doing with it. (UROP student)*

A few students demonstrated even greater independence in generating their own ideas for a research project, yet still depended on the support and guidance of their advisor when they faced methodological problems. These students typically had several years or summers of research experience.

> *When I was going to apply for [the UROP] grant, I sort of got a little bit more independent in the lab. [My advisor] said, "Well, what do you want to do?" And I said, "I want to do this, and I want to start with this," and then I kind of ran from there. And then we've had some problems with methodology, things like that. I've gone back, we've*

sort of re-consulted and reconfigured. He's got the experience of a lot of these other techniques that I don't have, so if there's something we can do that I don't know about, he can always just point me in the right direction. (UROP student)

Traditionally, the indicator of an authentic research experience is the production of publishable results. Almost all students—with the exception of the two students who were only involved in project set-up—reported that they engaged in research that could lead to publishable findings. Undergraduate research students rarely have the opportunity to present or publish (Hunter et al., 2007); however, a few BSI students reported that they had the opportunity to disseminate their research results to a broader scientific community. Three students reported that they had co-authored a peer-reviewed paper, one student had published in an undergraduate journal, and one student had presented at a professional conference. However, as we have argued elsewhere, while these opportunities to share scientific work are authentic in form and process, they must be authentically earned. Such opportunities arise only when students' work has reached a high level of completion and reliability, and has already passed through peer review by the research group and P.I.. Thus we are not arguing that opportunities for scholarly communication should be artificially created—just that they are valuable when they do occur.

What is striking is that men seemed to have greater access to participation in academic scholarship than women—of the five students who engaged in academic scholarship, only one was a woman. This gender discrepancy was independent of the amount of time that students had spent in the lab: women with extensive research experience were still less likely to engage in academic scholarship than men with equivalent research backgrounds. However, we cannot assert that gender bias was at hand because the numbers of students involved was so small. Nor did we detect this discrepancy in the URSSA survey administered in the spring of 2008 (Thiry & Laursen, 2009). Nonetheless, this evidence raises concerns. Undergraduate womens' perceptions of isolation and gender discrimination in the scientific disciplines has been well documented (Brainerd & Carlin, 2001; Bunderson & Christianson, 1995; Cohoon, 1998; Erwin & Mauretto, 1998; Margolis & Fisher, 2002; Sax et al., 2006; Seymour & Hewitt, 1997), thus we caution the BSI staff to be alert to whether women have the same access to scholarly opportunities as men.

In conclusion, almost 90% of students engaged in authentic research activities. The differences in novice and more advanced students' comments highlight undergraduate researchers' progression toward greater independence and responsibility in research work. Nearly all students were able to make intellectual contributions to their research project; a small fraction of students were not challenged and did not advance to greater responsibility. Advisor training should emphasize the importance of selecting projects that are appropriate for students' developmental level and should stress that novice students be continually guided toward greater independence and responsibility in the lab. For instance, some BURST students—and a few UROP students—could have been more involved with data analysis and problem-solving than they were. More experienced students should have greater responsibility for their projects and more input into experimental design and modification than novice students.

Even students engaged in unchallenging "busy work" activities did so in service of setting up a lab that will conduct authentic research. "Grunt" work—such as laboratory set-up or prep work—is occasionally a part of the research process, and students will encounter these tasks during their research placements. However, advisors could provide better learning opportunities for students engaged in these routine tasks, for instance, encouraging students to think critically about the decisions made during the lab set-up process. Decisions about laboratory equipment or research preparation are, at heart, methodological decisions, so students could learn by thinking critically about the choices at hand and having some autonomy to explore and compare equipment options, etc. Students may begin to see the relationship between laboratory equipment and experimental design; in essence, that equipment capabilities influence the methodology of an experiment and methodological choices will influence the equipment needed. It may take longer to set up a lab by talking through important decisions with students and granting them input into the process, but these actions will also help to shape students' abilities to think and work scientifically. Thus we are not arguing that students should never engage in routine or "busy work" tasks; rather, with forethought, such tasks can be crafted by advisors to encourage scientific thinking and reflection.

Advising and Lab Interactions

As noted, our prior research and evaluation work has indicated that the authenticity of scientific tasks and the quality of advising are integral components of a good UR experience (Coates et al, 2006; Thiry et al., 2009). Student outcomes, particularly in terms of intellectual and professional gains, are strongly tied to students' opportunities to engage in "real" science under the guidance of a more experienced scientist. Thus we investigated the quality and quantity of guidance and support received by students. As with students' observations about their gains from research, over 90% of students' comments about their advisors and lab interactions were positive. Thus we do not intend to overemphasize the small fraction of students with poor advising relationships; yet their experiences are instructive as to the ways in which advising can be ineffective. In the following section, we discuss students' interactions with their advisors and lab groups. We differentiate between primary advisors—the scientist with whom the student worked most closely—and the project's principal investigator, or P.I., generally the lab director. In a few cases, the P.I. also served as the student's primary advisor.

On the whole, students were very satisfied with their interactions with their advisors; a finding corroborated by the URSSA survey (Thiry & Laursen, 2009). Scientists at a variety of career stages served as advisors to BSI students. BURST students, perhaps due to their own novice status, were more likely to have a graduate student as a primary advisor (11 BURST students had graduate student advisors); while UROP students were more likely to have a postdoc, research associate, or the P.I. as a primary advisor (11 UROP students had a senior scientist as a advisor). Generally—with the exception of students who named the P.I. as their primary advisor—students had less interaction with the project P.I. than with their primary advisor.

Almost all students noted that they interacted regularly with their primary advisor; most of these students met with their primary advisor every time they were in the lab. However, one UROP and one BURST student reported that they had very little interaction with their primary advisor. The following comments from these two students indicate their isolation from more experienced scientists.

> *Most of the time, at this point [the P.I.] is trying, or she's pursuing several large grants to buy expensive toys. (LAUGHS) So most of the time I am actually by myself [in the lab] (BURST student)*
>
> *[Lab meetings] weren't a priority to our advisor. Our lab is really small, and very heavily undergraduate. The postdoc is sufficiently busy that he has a little bit of time to help us, but very, very little. We've kind of routinely been about three to four undergrads and we would be meeting on our own. And while that was useful, I mean there is only so much an undergrad knows. (UROP student)*

Almost all students noted that they spent an adequate amount of time with their primary advisors. However, a few students did not spend enough time with more senior scientists and reported less adequate guidance and supervision in the lab. Though these numbers are quite small, students' quantity of time with their advisors may be as important as quality of time. On the URSSA survey, the quantity of time that students spent with their advisors was significantly correlated to intellectual gains and overall satisfaction with the research experience (Thiry & Laursen, 2009). Thus advisor training should emphasize that both quantity *and* quality of time with a student are important elements in achieving student gains.

We will now discuss the types of support that advisors provided to students. Students identified three primary areas in which they received support from their advisors:

- ***Intellectual support*** on their research project (e.g. help with problem-solving or identifying the "next steps" of the experiment)
- ***Professional socialization***, (e.g. transmitting the values and norms of the profession, along with essential disciplinary knowledge and skills)
- ***Personal/emotional support*** (e.g. general comments that advisor is supportive, accessible, friendly, takes an interest in me, etc.)

We will use the above categories to frame our discussion of students' interactions with their advisors and lab groups. First we will briefly discuss the nature of support provided by primary advisors and P.I.s and then we will provide an extended discussion of the nature of support within each of the above categories.

Summary of interactions with primary advisor

As noted previously, students were highly satisfied with their interactions with their advisors: 92% of students' comments about their primary advisors were positive. Students also discussed at length the nature of the support provided by their primary advisor. Students' comments indicated the following ways in which primary advisors supported students:

- 44% of all students' comments referenced *professional socialization*
- 35% of students' comments referenced *intellectual support* and guidance on a project
- 13% of students' comments referenced *personal/emotional support*
- 7% of students' comments referenced *setting expectations and guidelines*

There were very few negative comments about interactions with primary advisors. However, one-quarter of these comments referenced a lack of intellectual support, 31% referenced a lack of personal/emotional support, and 37% referenced socialization.

Summary of gains from interactions with P.I.

Although students reported less interaction with their P.I.s than their primary advisors, they were largely satisfied with the quality of interaction with their P.I.s. Indeed, 94% of students' comments about their interactions with their P.I.s were positive.

- 39% of students' comments referenced *intellectual support* and guidance on a project
- 32% of all students' comments referenced *professional socialization*
- 26% of students' comments referenced *personal/emotional support*
- 3% of students' comments referenced *setting expectations and guidelines*

Students made few negative comments about interactions with the P.I. However, of these comments, 33% of negative comments referenced a lack of intellectual support, 44% referenced a lack of personal/emotional support, and 22% referenced a lack of professional socialization. When possible, we include in our discussion students' negative comments because they are informative concerning students' poor research experiences, while keeping in mind their low numbers. We now discuss each category of support in greater detail.

Professional Socialization

By socialization we mean the cultural and social process through which individuals join a profession. Through the process of socialization, novices learn the formal policies, rules, and requirements of the community as well as the informal norms, values, and behaviors. Additionally, students receive an "anchoring," or disciplinary mooring (DeWelde & Laursen, 2008) by acquiring conceptual knowledge, skills, and disciplinary understanding.

Overall, students received more socialization benefits from their primary advisors than from P.I.s, perhaps because they spent more time with their primary advisors and were able to observe and interact with them more closely. Primary advisors and P.I.s helped to socialize students into the profession and into the field in several ways:

- ***Disciplinary mooring***: Providing information and guidance about the discipline or scientific careers; explaining important conceptual or theoretical ideas in the discipline; providing advice about courses, graduate school, or the life as a research scientist;
- ***Teaching new skills***: Teaching data collection and analysis techniques; helping with posters or scientific writing; helping students to prepare for presentations
- ***Modeling and guiding scientific behavior:*** Guiding students toward greater independence and responsibility in the lab; helping students to accept that setbacks and failure are a part of the research process; portraying by example the professional practice of scientists

- ***Fostering identity development***: Serving as a role model; working side-by-side with student; offering students the opportunity to participate in academic scholarship through publication or presentation

Primary advisors and P.I.s differed little in the ways that they supported the professional socialization of students, as demonstrated in Table 1. The most common category discussed by students was disciplinary "mooring," or educating students about key disciplinary concepts as well as career paths within the discipline. Other categories, such as socialization into the behaviors of scientists or fostering an identity as a scientist were not as prominent in student reports.

Table 1. Socialization benefits from students' interactions with primary advisors and P.I.s.

Method of Socialization	**Primary advisor** % of student comments	**P.I.** % of student comments
Disciplinary mooring	37%	39%
Teaching new skills	27%	28%
Guiding behavior	16%	11%
Fostering identity development	13%	9%
Providing knowledge and information about scientific careers	7%	13%
TOTAL	*100%*	*100%*

We now discuss each method of professional socialization in greater detail.

Disciplinary Mooring

An "anchoring," or mooring into the discipline was the most common outcome from students' interactions with primary advisors or P.I.s. Senior scientists introduced students to the big picture of their project, and to major theories and concepts in their field. Students needed to be socialized into this habit of thinking in terms of big ideas before they could engage in higher-level scientific thinking. Advisors served as stewards of the discipline, introducing students to important ideas and concepts in the field. This was a prominent category for both BURST and UROP students, constituting 23% of UROP students' and 34% of BURST students' comments about support from their advisors.

Students reported that their primary advisor helped them to understand journal articles by discussing key concepts and explaining important ideas in lay language.

> *We talked about it. I read through some of it, but there was just a lot of terminology, I had no idea what it meant. And I tried looking it up, but it got really confusing. And so she would re-interpret it into more English, so that I'd understand it better. (BURST student)*

Some primary advisors made great efforts to ensure that students understood the theory and concepts guiding their projects. In the comment below, a student describes the multiple ways in which her advisor tried to help her understand significant disciplinary concepts.

> *She did a great job of explaining anything that we were doing, going into detail, and explaining exactly what it meant. And if I didn't understand, I felt comfortable asking her questions, and if it didn't make sense when we would talk about it, she would draw pictures. So she wouldn't just try and say the same things over and over, and hope I get it the next time. But she'd go about it in a different way. (BURST student)*

Students also reported that P.I.s helped them to understand how their project related to the discipline or field.

> *The first part is at lab meetings, listening to everybody talk about how this might be related to everything else. Especially [the P.I.], he's really good at backing out and taking a look at how it's related to everything else. (UROP student)*

Many students were not familiar with the important concepts in their disciplines and their disciplinary knowledge was enhanced by discussions with P.I.s or primary advisors.

> *I get curious about how the biology side of it works. And I can read these papers and they explain a little bit about how the signaling works, but when I talk to [the P.I.] about it, she explains it a little bit more. So on one side of it, I'm learning more about the biology behind my project. And then on the other side I learn better technique, "Here's the logic behind why we do this assay, or this data analysis." So a lot of it is just the background behind it, and the motivation for why we're doing these things… 'cause when I started my project I hadn't even started taking O-chem yet. So, I needed a lot of help understanding the biology and the chemistry behind it. (UROP student)*

Only one student mentioned that his P.I. had not been helpful in orienting him to the field or to the "big picture" of the research project and its fit within the discipline. This particular student spent most of his year helping to set up a lab and not actually conducting authentic research. The nature of the work did not generate higher-level intellectual discussions about the discipline or field. In response to a question about what he learned about the discipline from his research experience, the student replied:

> *I haven't had as much [orientation to the big picture] as I would have liked.... So as far as directing us, and being able to get the lab set up and whatnot, she's been right there, definitely. But as far as getting to do some other research beyond setting it up, I haven't been able to do as much as I would have liked. I feel as though what we've been doing hasn't been that much research, as much as it's just been kind of trying to get our bearings straight, and laying the tracks down to do research. To kind of get things set up, so that research can actually be done more so in the future. (BURST student, negative observation)*

Three students discussed a lack of socialization into the guiding concepts of the discipline from their primary advisors. These comments primarily concerned a lack of help in reading and understanding journal articles or a lack of theoretical discussion with advisors. In the comment below, a student mentioned that she was given journal articles but did not discuss them in depth with her advisor or others in the lab. Students reported greater gains from reading journal articles when their advisors discussed the article with the student, especially when the advisor initiated the discussion about the article. Some novice students felt intimidated about asking theoretical questions about journal articles, or did not know how to read in ways that clarified their questions. In the comment below, a student describes a lack of interaction and discussion about journal articles with other scientists in the lab.

> *I didn't specifically [discuss the journal articles with my advisor], it was more sort of, "You can read these when you have time, and then if you have questions we can discuss them." (BURST student, negative observation)*

Knowledge and information about scientific careers and graduate school

Primary advisors and P.I.s provided advice and information about coursework, graduate school, and scientific career options. UROP students made three times the number of comments of BURST students in this sub-category.

Primary advisors provided practical advice about graduate school and the appropriate courses to take for certain educational paths.

> *[I've talked about grad school] especially with [my primary advisor]. I've talked to her about certain things that I'm interested in, what I'd be thinking about doing. She's just always been really supportive of anything that I've said that I was interested in, and she'd give me advice about, "Well, these are the classes you should be taking in order to be able to put that on your transcript." (UROP student)*

Graduate student advisors shared their experiences and motivations for pursuing graduate degrees.

> *I talked to him about what made him want to do a Ph.D., and basically he told me that if he were to go out into industry right now, in ten years he'd wish he had his Ph.D., so he said he might as well get the work done now and not have to worry about it later. (UROP student)*

Some P.I.s encouraged students to pursue graduate school and specifically designed projects to prepare students for graduate studies and enhance their graduate school applications.

> *My P.I. has really sat down and talked to me about, "Okay, well, you're not going to be at CU forever, and if you're going to go on to graduate school, how can we set this up so that the project looks really good?" He's really open about trying to make sure that I keep all my options open and that I make the right decision for my future, but right now I*

> *just really don't know where I wanna go…. He's really great about pushing me to try to apply to grad school and make sure that my grades are up. (UROP student)*

P.I.s also had more extensive professional networks than students' primary advisors—who were often graduate students or postdoctoral researchers—that helped students broaden their options for graduate school.

> *I'm talking with [my P.I.] about options for graduate school, so he has a lot of contacts in research in [this field], so pretty much I'll be going on with this. (UROP student)*

Teaching New Skills

Senior scientists also helped students to develop the skills necessary to become successful scientific researchers. Primary advisors and P.I.s taught students data collection and analysis techniques and helped them to develop scientific writing and oral presentation skills. Their lab group training built upon the knowledge and skills that students had gained from program workshops.

Primary advisors often introduced students to the laboratory techniques required for their project. BURST students, in particular, needed guidance and training in the use of laboratory equipment.

> *[My advisor] was the main person that helped me with the staining and everything. So at the beginning, she taught me how to use the microscope, and photograph tissue, all of that. And then there were grad students that taught me how to slice frozen tissue, and to put on slides before you stain them. Mostly it was [my advisor] that helped me with using machinery. (BURST student)*

Primary advisors also provided instruction in analysis techniques and helped students to interpret data.

> *Earlier this week, we were taking the raw data we gathered from a subject's visit, and we had to put it into a program to graph it out, so that we can put all the data together from other subjects. And so the graduate student was teaching me how to use the graphing program. And he would teach me with one set of data, and then I would try to do it while he was sitting there with another set, to make sure I understood. And then we would look at the graphs that we had made, and try to explain why that was happening. (BURST student)*

A BURST student contrasted the teaching roles of her primary advisor and P.I.. While her primary advisor provided instruction in lab procedures and equipment, the P.I. helped to orient the student to the "big picture" of the project and explained important theoretical concepts.

> *[My primary advisor] is teaching less on the level that she is, and more on the level of lab procedure-type things. Like pouring gels, and setting up different procedures, and stuff like that… and [the P.I.] is more of a vision-type lady. (BURST student)*

Some primary advisors and P.I.s also helped UROP students with the design and preparation of their posters. Most students had never created a scientific poster before and benefited from the expertise of senior members of their lab group.

> *I was doing the poster with my postdoc, so I had a little bit of an idea of what I was supposed to do. He presented me with an example background, like a skeleton key, or a template. In the end I actually ended up re-doing the whole thing, so I didn't use what he gave me, but I had a good idea of how it was supposed to look on the poster. He helped me out a lot with that. Overall, I just feel fortunate to have such good interaction between me and the postdocs. (UROP student)*

Modeling and guiding scientific behavior

Senior personnel guided and supported students in developing the behaviors and temperament that are necessary to become scientific researchers. Advisors guided students toward greater independence and responsibility on their projects and helped them to accept that setbacks and failures are inherent to the research process. The nature of this type of support differed between BURST and UROP students. For example, BURST students needed guidance in conducting lab procedures independently, while UROP students needed support in running their own experiments or determining the next steps of an experiment.

In the following comment, a BURST student describes the process through which she gained independence in conducting basic lab procedures.

> *They let us do a lot of stuff on our own. They teach us how to do it, and then basically the undergraduates do certain parts of it by themselves. And so, I [learn to] rely on myself, and my ability to make decisions for that. (BURST student)*

While BURST students discussed moving toward greater independence in daily tasks and basic lab procedures, UROP students discussed beginning to think independently about a project. Advisors helped to encourage independent thinking by welcoming students' input and discussing students' ideas. In the comment below, a UROP student describes the balance between support and independence in his relationship with his primary advisor.

> *He's very hands-on. But he's also willing to let me have a little bit of space in the lab. And it's gotten to the point where we'll sit down and we'll talk about something and he'll say, "I want to go in this direction." And I'll say, "I think we should go in this direction." And we'll sort of hash something out and he'll say, "Go do it." I'll go do it, I'll come back, we'll talk about the results and then we'll go from there. So, it's really good and he's always available if I ever need to get a hold of him. (UROP student)*

Senior scientists also helped students to become independent by encouraging initiative and motivation. Advisors' expectations were integral to students' outcomes; for instance, some advisors *expected* students to be independent and take initiative on their projects, which, indeed, fostered greater independence in students.

> *I think she is a good P.I. in that she wants me to be self-motivated. She's not gonna just say, "Okay, I want you to do this, now get it done." (UROP student)*

Advisors and P.I.s also helped students to accept that setbacks are a part of the research process. They encouraged their protégés to develop perseverance in the face of failure and shared their own experiences with failure in the lab.

> *A couple times [it] was kinda discouraging. [The P.I.] and both the grad students, they're really encouraging and they're reminding me, "This is science, don't take it personally, just keep trying," and they've been giving me different tips to see if I can make it work. So then trying that—and it has been frustrating—but at the same time, it's okay 'cause I can put it down for a while. The project that I was working on with making the DNA, I was talking with my P.I. and she told me her past experiences, she was doing something and that she just put it down for a while and then picked it back up—just to let your brain un-freeze up and think about it again. (UROP student)*

While almost all of students' comments were positive, three students did make negative comments about a lack of guidance or role modeling from their advisors. These comments referenced a lack of help and support in preparing the UROP poster, and close supervision that did not allow for independence or autonomy. In the mixed observation below, a student mentioned that she had minimal input into the nature of her duties or role in the research group. Her advisor did not provide her with many opportunities for independent thinking.

> *Most of the time, there's just so many things in there I can't—well, I can proactively decide to do some things, but most of the time it's things directly that she's asked me to do. (BURST student, mixed observation)*

Identity development

The final professional socialization outcome from students' interactions with senior scientists was developing an identity as a scientist. For instance, students were socialized into the peer review process from senior scientists' feedback and critique of their work. Some advisors also encouraged students to engage in academic scholarship by publishing or presenting research findings. Senior scientists also acted as role models as students learned about the life and work of scientists through observation and discussions. For the most part, comments in the sub-category of "identity development" came from experienced UROP students.

Senior scientists offered constructive critique of student work, helping students to accept that critique is standard practice within science and should not be taken personally.

> *Especially with that literature review I had to write a couple years ago, I wrote it with [my advisor], and she was just brutal with me! I would write a draft, and then I'd basically go in and she'd be like, "This is crap." (LAUGHS) So she was really tough on me, but on the other hand, that was probably the best thing she could have done for me. It really forced me to, like, "Okay, what am I...?" You know, "I need to sit down and think about this more." (UROP student)*

Constructive feedback and modeling of peer review provided by senior personnel helped students to sharpen their critical thinking and writing abilities.

> *We did a lot of revision, and me having to go back and fix it, and I'd return it to him. And I know that sometimes, people will write a proposal and the P.I. will look at it and just change it all. And then, he doesn't make sure that you learn what you did wrong. And my P.I. drove into me, why is my hypothesis wrong. Or, why is my introduction – what is it missing. (UROP student, discussing UROP proposal)*

Some advisors or P.I.s also encouraged students to participate in academic scholarship.

> *So I think right now, he's pretty much doing everything he can to make sure that this project, I can get what I need out of it and make sure I get published and… I think he's doing a pretty awesome job. (UROP student)*

In sum, students received important professional socialization benefits from their everyday interactions with advisors and P.I.s. Advisors educated students about the theoretical foundations of the discipline, taught foundational skills, guided students toward independent behavior, and served as models of professional practice. On the other hand, students' interactions with their advisors were not helpful when they were simply directed in routine tasks and not allowed to engage in independent work or thought.

Intellectual support on project

The second category of advisor support was intellectual support on the research project. Advisors helped students by answering questions, explaining research designs and protocols, helping with problem-solving and troubleshooting, assisting with data analysis and interpretation, and helping students to understand research findings. Students' comments about intellectual support from their advisors were overwhelmingly positive; only four students made negative comments. All of these comments referenced a lack of support in problem-solving or a lack of opportunity to discuss research findings with other scientists.

Much like students' gains from the research experience, students' comments about mentoring demonstrate the progression of intellectual guidance and support needed as they advance from novice to experienced status. For example, novice students need to develop a basic understanding of the project and its procedures, while more advanced students need to develop problem-solving skills and the ability to plan the next steps of an experiment, and even more advanced students need support in generating research questions or experimental design. The range of students' intellectual needs maps onto Bloom's Taxonomy of Learning (Bloom, 1956). The taxonomy divides knowledge into three groups of increasingly demanding cognitive tasks, from factual recall through conceptual comprehension to real-world application, plus three additional high-level tasks: analysis, synthesis, and evaluation. Bloom's categories are defined as follows:

- *Knowledge:* Recall of facts or information

- *Comprehension*: Understanding the meaning of concepts or problems
- *Application*: Using a concept or theory in a new situation, applying classroom learning to a "real-world" setting
- *Analysis*: Separating materials or concepts into their component parts, understanding organizational structure, distinguishing between facts and inferences
- *Synthesis*: Building a structure or pattern from diverse materials or elements, creating a new meaning or structure
- *Evaluation*: Judgment or evaluation of the value of ideas or materials

Table 2. Students' intellectual needs for support from primary advisors and P.I.s

Category of Bloom's Taxonomy of Learning	**Support provided by primary advisor,** % of comments	**Support provided by P.I.,** % of comments
Knowledge	34%	15%
Comprehension	24%	9%
Application	22%	40%
Analysis	8%	14%
Synthesis	11%	16%
Evaluation	1%	2%
TOTAL	*100%*	*100%*

Table 2 demonstrates the distribution of students' comments regarding the intellectual support provided by their primary advisor or P.I.. The majority of students' comments fell within the lower tiers of Bloom's Taxonomy of Learning; however, students also made a fair number of comments within higher-level domains, such as analysis or synthesis. Unlike other categories of support, the nature of support provided by primary advisors and P.I.s differed slightly. Primary advisors provided greater amounts of support in the lower-level scientific thinking skills needed to function in the laboratory, such as knowledge and information, while P.I.s more often provided higher-level intellectual support in application, analysis and synthesis—those skills involved in making sense from findings.

We now discuss in greater detail the intellectual support provided by senior scientists within each domain of Bloom's Taxonomy of Learning.

Knowledge

The most basic category of Bloom's Taxonomy of Learning is knowledge, including learning facts and information about a field. Learners may also gain knowledge of the underlying principles or theories that guide a field or discipline. Gaining knowledge is a necessary first step toward more advanced intellectual activities.

Senior scientists helped to increase students' basic knowledge by answering questions and sharing facts and information. Answering questions and providing information was particularly beneficial at the beginning of the research project when students were inundated with information about the project, lab procedures and research protocols.

> *We definitely get so much information in the beginning, that I couldn't remember it all. But they were willing to answer my questions—it's just, I didn't remember a lot of things, because it was just so much at the beginning. (BURST student)*

> *Just sort of being there to answer my questions, 'cause I've never done research before, so, it really helps that we have somebody there all the time that can constantly answer all of the questions. And she also is the one that shows me how to use new machines and new methods I haven't done before. (UROP student)*

Comprehension

Within this category, learners begin to understand the meaning and significance of information from the "knowledge" category—why those facts are important. To demonstrate understanding, learners should be able to re-state knowledge, information, or conceptual principles in their own words. Learners should also be able to classify, generalize, or summarize information related to their research projects.

Senior scientists helped to increase students' understanding of their research projects. Senior personnel in the lab group provided explanations of techniques and research design, and helped students to understand research findings. Some provided explanations about why particular techniques were used or why they were important.

> *I'm the kind of person in the lab where I need to understand what I'm doing. I need someone to explain to me, why this technique is important, or, even what the technique is doing. (LAUGHS) And, I'm very curious about things, and so I usually don't hesitate at all to ask questions. So if anything (LAUGHS), I'd like to ask more questions, but, I don't want to be a burden, be that guy who asks all the questions. (UROP student)*

P.I.s, in particular, were helpful in orienting students to the work of the lab overall. Students needed to understand their individual project and how it related to other work in the lab.

> *[The P.I.] had a slide show ready on her computer when I walked into her office, and she was very much like, "Here are the three projects my lab worked on, here is how they're all related, this is what we're focusing on." And, it was very clear, and she was very good at explaining it. So from the get-go it was like, "Okay, this is a really good P.I., who is really open to educating me." (UROP student)*

Application

The third category of Bloom's Taxonomy involves applying previously learned information to new situations or to solve problems. In the lab, undergraduate researchers applied their prior knowledge and understanding to a new experiment, technique, or problem. Outcomes in this category may involve the ability to solve problems correctly, and to apply new methods or procedures to a problem.

UR students needed support from senior scientists to apply their knowledge and understanding to their research. Senior personnel worked closely with students to help them apply their knowledge about laboratory procedures and protocols to solve research problems. Students saw developing their problem-solving abilities as a critical step in becoming independent in the lab. Observing professional practice and engaging in collegial discussions were integral in helping students to apply their learning to research problems.

> *At this point now, I'm asking a lot of advice or questions about how did they troubleshoot and find this optimal way? At the beginning, I was just always getting standardized recipes. [My advisor]would tell me how much to put in. 'Cause I was just learning, I didn't question it, because I was barely absorbing everything. But this time I'm understanding. I get what's going on, and especially when I run into problems, I'm asking, "How did you know this was the optimal time or optimal amount?" Then they tell me, "I tried this and I tried this." I'm asking a lot of questions like that to prepare myself for grad school, in which I might have a professor that doesn't provide as much guidance. I'm watching them do stuff and seeing how they become independent and run their own experiment. (UROP student)*

> *I talked with [the P.I.] the most at the beginning, because she's kind of the specialist on the sensor as well as the microscope. So I brought up some certain trends I was seeing, and she helped me look at it and she told me, you might look for this, and that's helped me go back to my experiment. 'Cause we can go back to the experiment on the computer, and look at it in a time frame to see what was happening. So I was able to learn how to do that and figure out how to look at each cell individually and if it's an outlier what do I do? So I was able to troubleshoot that with [the P.I.]. (UROP student)*

There were very few comments related to a lack of intellectual support from advisors, but they all fell within the realm of "application." A few students recounted a lack of support in trouble-shooting problems or setbacks, or a lack of opportunity to discuss their research progress with others. Therefore, the realm of "application" seems to be a stumbling block for students' intellectual advancement in that it is a more challenging cognitive level and advisors may not always adequately support students in their advancement to this level.

One student, in particular, had a poor experience with her P.I. She felt unsupported on her research project for over a year, and finally concluded on her own that the experiment had gone in the wrong direction. She felt that she had wasted a year on unproductive research by not being able to discuss the progress of her project with others, and felt that she was intellectually and socially isolated.

> *[The P.I.] doesn't know the meaning of the word mentor, that concept is totally foreign to him. For example, he's very willing to let people go off on their own, and work on their own project. If you are on a project, and you're doing well, and things are working for you, you are gonna have an amazing experience in this person's lab. But you're gonna run into problems if things aren't working. And then he is completely unwilling to help, he just yells because it's your fault that you can't get it. (UROP student)*

Analysis

"Analysis" is the fourth category in Bloom's Taxonomy of Learning and involves breaking down a greater whole into its component parts in an effort to understand its underlying structure. This may include examining information or data to draw conclusions, make inferences, or support claims. Senior scientists taught students basic data analysis techniques but more importantly, how to decide what technique to use in specific situations.

> *Yesterday I met with [my advisor] and I showed him a revised data set and graph. And then he gave me a suggestion to put it into bar graphs, because it's visually easy to see differences. So that's kind of been nice is… to help me use easier ways to identify what's going on and showing me how to do some of the statistical tests and what the meaning is. (UROP student)*

As noted in the gains analysis in the "thinking and working like a scientist" category, analysis tasks served as another intellectual stumbling block for students. Data analysis and interpretation requires higher-order scientific thinking skills, but not all students had the opportunity to participate in data analysis during their research experience. Some advisors simply conducted the data analysis themselves and did not offer students the opportunity to learn this skill.

Synthesis

The fifth category, "synthesis," describes the utilization of prior knowledge to produce something new. Unlike "application," in which prior knowledge is used to *understand* a new situation or solve a problem, synthesis involves the *production* of something new and unique. For example, designing, experimenting, hypothesizing, reorganizing and integrating are all activities that fall within the "synthesis" category.

Applied to undergraduate research, synthesis involves generating research ideas and questions, developing research designs, and interpreting data analysis results. Primary advisors and P.I.s helped students to modify experiments to test hypotheses.

> *I would talk [the interpretation of findings] over with them.... Well, I'd try to come up with a couple things on my own, and then I would show them, and talk to them about it. And if we could or could not come up with anything, just bring the results themselves to the lab meeting, and put 'em up on the overhead projector and then we would have a group discussion about what it might mean. (UROP student)*

The following comment illustrates the way that a P.I. guided a student toward an understanding rather than giving him a direct answer, to facilitate critical thinking. The student reported that this helped him to think more deeply about the project itself and his next steps in the experiment.

> *He's a great professor in regards to, he's very challenging. So when you have a question he's kind of like Socrates in a way. He, just asks your question back to you in some kind of way, and helps you along with kind of answering that question. So he doesn't give you the answer straight out, he helps you work through it. So when you start to have answers, he'll ask you questions all the time, and it's kind of nice. It's a little intimidating*

> *at first, but he's really nice about it. So you realize it's just trying to get you thinking about what you're doing. So when you answer a question, he's got another question waiting for you. He's always challenging you to kind of think up into the next step, and that's definitely nice. (UROP student)*

Another student noted the ways in which her primary advisor helped her think beyond data analysis to the implications of the findings and the next steps to take in the experiment. In this manner, the advisor encouraged the student to synthesize findings and place them in the context of the project overall. The comment below is also an example of how effective advisors fostered a balance between independence and support; the student got as far as she could on her own and then turned to her advisor for guidance in the “bigger picture” of the project.

> *We talk over the direction that my project's going in. For example, I just recently collected a whole bunch of data, and I'm learning how to use this new program that helps me graph things. I'll do the best I can to get through all of the data, and then I'll go and give it to her and we'll look over it together and she'll say, "Okay, so, another way to look for outliers would be… given, this data analysis." Or we'll look over it together and we'll say, "Alright, is this significant, or what other experiments do I need to do in the future to make my data more convincing?" Or which experiments am I going to move on to next? We just talk about where we're going in the future. (UROP student)*

A student recounted his own transition from novice to collaborator. His advisor explained the tenets of experimental design and he used that knowledge to guide the future direction of the research project.

> *He pretty much explained to me experimental design and how it works, different variables and different controls used in experiments. And then after I got a good grasp on that, I was able to help him design some future experiments, using the knowledge that he gave me. (UROP student)*

The quotations above indicate how advisors helped to facilitate higher-order scientific thinking skills in students. Two-thirds of the comments in this category came from UROP students. However, even advanced students needed support and guidance in the higher-level domain of experimental design and synthesis of research findings. With good support and guidance, balanced with the freedom to think independently, students were able to develop and hone their higher-order scientific thinking abilities.

Evaluation

Students made few comments that referred to this final domain in Bloom’s taxonomy. “Evaluation” refers to judging the merit, worth, or value of information or materials. Activities within this category may include using external criteria to judge the merit of scientific ideas, products, or information; critiquing ideas; or offering recommendations and justifications.

A common scientific activity in this category is the scholarly process of peer review and critique. For instance, scientists may critique or find flaws in methodology or experimental design, evaluate competing interpretations of findings, and review or critique scholarly works. Some students observed such practices within this domain through their participation in lab meetings, while others received feedback or critique on their posters or scientific writing from scientists in their lab, or engaged in the peer review process by co-authoring an article. However, students rarely provided critique or evaluation themselves: they may have been the recipients of scholarly critique but rarely practiced scholarly critique themselves.

Students' lack of participation in evaluative activities is unsurprising given that these practices involve a very demanding level of scientific thinking. Most undergraduates were simply not ready to offer critique of scholarly works or experimental methodology. However, advisors could push students toward more evaluative thinking by asking for their feedback on methodological debates or competing interpretations of research findings. The very act of formulating hypotheses or evaluating and defending competing ideas—even if their assumptions are incorrect—may facilitate higher-level reflection in students as students come to understand why their ideas or assumptions are correct or mistaken through dialogue with senior scientists. It also makes clear the fact that this is a normal part of professional practice.

Therefore, while students observed other scientists engage in evaluative discussions, they rarely *offered* this level of feedback or critique themselves. In the comment below, a student describes questioning his advisor about the validity of a scientific argument.

> *Sometimes I'll ask [my advisor] for help on specific things, if he has any ideas on how to improve specific experiments. But usually it's a big-picture question on what directions he'd like me to go in or whether he thinks it's a valid argument or something like that. (UROP student)*

In sum, intellectual support was one of students' primary needs from their advisors. Students needed both basic knowledge about their project and support in higher-level analytic and interpretive skills. Although the majority of students' comments about intellectual support fell within the lower-level cognitive domains, there were also a substantial number of comments in the higher-level domains of analysis and synthesis. Nearly all of students' negative comments described a lack of intellectual support for tasks in the "application" or "analysis" domains, such as a lack of support in problem-solving or lack of opportunity to engage in data analysis. If students have no chance to attempt tasks in these intellectual domains, they cannot learn to analyze, interpret and evaluate evidence—the core of the scientific enterprise.

On the whole, UROP students discussed intellectual support more often than BURST students, yet the nature of needs differed between UROP and BURST students. BURST students' comments referred primarily to lower-level cognitive domains of knowledge and comprehension, although some students had moved into application and analysis. The more advanced UROP students discussed the higher-level domains of application, analysis, and synthesis more often. For example, 57% of BURST students' comments referenced knowledge or comprehension, while most of the remainder of their comments focused on the third category, application. In contrast, 51% of UROP students' comments referenced the higher-order thinking skills of analysis, synthesis and evaluation. These differences demonstrate the progression of students' needs for intellectual support, from basic facts and understanding of their research project, to a need to analyze, make sense of, and interpret data.

The practice of science depends on the evaluation of competing ideas, so undergraduate research students also need to be supported and socialized into the practice of peer review critique, evaluation, and argumentation. While many students observed scientists engage in these practices—which was highly beneficial to their learning—they did not often participate themselves. Students frequently discussed research findings with their advisors, but these discussions rarely reached the status of "evaluation." It is interesting to consider how inexperienced students might be more engaged in this type of higher-order scientific thinking.

Personal/emotional support

Another important source of support for UR students was personal and emotional support from advisors. We identified two major ways in which advisors supported students' personal growth and development, which we describe as "receptivity," and "support or guidance." As with the other categories of advisor support, the proportion of negative comments regarding personal/emotional support was minor. These domains are modeled after, though do not exactly replicate, Bloom's taxonomy in the affective domain. We now discuss these two domains.

Receptivity

The foundation of collegial interactions within a lab group was built upon the *receptivity* of both advisors and students. Receptivity refers to the initial steps that people take to build a working relationship, such as being open, accessible, friendly, patient, respectful, and committed to their joint work. Building a foundation of trust and collegiality with advisors and peers helped students to feel comfortable in the lab, and in taking the intellectual risks that are necessary to develop and grow as a scientist.

Some novice students felt intimidated at the beginning of their research experience because they did not want to appear inexperienced and unknowledgeable.

> *At first I was intimidated to ask for help. 'Cause it—you really want to—I mean, these people just hired you, and you really want to appear like you know what you're doing. (LAUGHS) And so I was kind of intimidated earlier on to ask a lot of questions, and maybe ask the wrong questions. But I think that that's really the only way that you can really pick up on what you're doing right, and what you're doing wrong, is by asking a lot of questions. And by not being intimidated to ask those questions. (BURST student)*

There were several ways by which advisors and others in the lab built collegial relationships with students and helped them to feel comfortable. P.I.s and advisors signaled to students that they were available and easily accessible.

> *[The P.I.] tells us, "If you have any questions just e-mail me, or schedule an appointment, or come to my office, I'm always available for you guys." (BURST student)*

P.I.s and advisors also signaled their availability to students by checking on them and asking if they have questions.

> *[The P.I.] is available, and he will come and ask me how things are going, and if I have any questions for him. (BURST student)*

Working closely with students and being willing to answer questions also established rapport with students and helped them to feel more comfortable with "expert" scientists.

> *What really helped me was just that my postdoc was always really available and always eager to answer all of my questions. I think just because I worked so closely with him from the beginning, I think that helped a lot. (UROP student)*

Advisors also helped to establish collegial relationships by being receptive to students' ideas. When students felt that their ideas and input were valued, they were more willing to take intellectual risks.

> *She's providing direction for me. But a lot of what we do is worked on together. So she'll have the final say, she's got the expertise, and the experience that I don't have. But she'll allow me to ask questions, or suggest ideas, or changes to the protocol. And she'll be really receptive to that. And, sometimes she'll use my ideas, other times she'll give an explanation why she would prefer to do it another way. (BURST student)*

Another student noted that his primary advisor's openness to his ideas created an environment in which they could collaborate productively.

> *It's definitely a mutual thing. I don't have any idea what I'm doing starting off, so she said, "This is a good way to start to do the kind of things that I would do if I were you." And then she goes, "If you have any better ideas, or any alternatives to this, and I feel that it's a good pathway, then I'll help, let you do it." And so that's how we [plan the next steps]. (UROP student)*

Students made a few negative comments in which they described senior personnel who were unavailable or inaccessible. The comment below reflects the losses to students' learning when advisors are unavailable and students are left to engage in meaningless tasks.

> *It's hard because of how much work [the P.I.] has to do. And I do very much like her as a person, but it's sometimes hard because she has her other focus, and so sometimes I don't do as much as I would like…. It's hard because she doesn't spend all that much time in the lab actually working, so most of the duties I have are not horribly 'researchy.' I'm not doing research all that often really, I'm mostly just doing upkeep things there. She's very helpful when she's around, it's just that she needs to get these grants, so that we can afford to do the research we're here to do, so it kind of puts us both in a bind. (BURST student, negative observation)*

Support and guidance

Students also required personal and emotional support and guidance from their advisors. Students benefited when they felt their advisors were committed to their progress and took an interest in their professional development.

> *She's got a lot of energy and excitement for her field, and she's a great teacher. And if you put a lot of work into her, she'll put a lot of work in for you. (UROP student)*

> *I think [the P.I.] is a really good investigator to be working with. He is really invested in the students in his lab, and he's very willing to help you with all different aspects of research and just things in general. And he's definitely been a really good part of the research experience. (BURST student)*

Advisors also provided personal and educational advice for students. Even more importantly, it was essential that students felt comfortable seeking advice from their advisors.

> *I even ask academic questions that are not even related to my research right now. I would be like, "Well I think I'll get a B in my class, should I drop the class?" and all this stuff. He's really comfortable to talk to. (BURST student)*

For some students, P.I.s provided higher-level intellectual support, while primary advisors were a source of personal and emotional support. In this way, students developed a more personal relationship with their advisors that was less hierarchical than traditional student-faculty relationships.

> *And sometimes it's become personal, he's one of the people I ask about advice to. He kinda guides me; he guides me in anything. Whereas [the P.I.] gives me troubleshooting advice. Or I update her on what's going on with the project and she's kinda like a mental support too. So she's more my mental support, and troubleshooter. And [my advisor]'s kinda the overall, well-rounded help. (UROP student)*

Primary advisors and P.I.s also demonstrated patience with students who were grappling with a steep learning curve at the beginning of the research experience.

> *She didn't make it like anything had to be rushed: "If you don't understand this we'll just wait, and, I'll help you understand it before we go on." Even in some of my classes, they make you feel like, "If you don't know this, you're stupid." And I never felt that way around her. So I think that helped me a lot. (BURST student)*

P.I.s and advisors expressed interested in students' work and progress.

> *Just the fact that he's around, and that I see him, and that I'm not afraid to talk to him, and there's probably no topic that I could not discuss with him. I think that's probably the thing that has helped me the most, just having somebody to connect with in the lab because he knows exactly what's going on in my project. I think, for other people that do research at this university a lot of times they only see their P.I. once a month or whenever*

> *they have to have a meeting or something like that. And I think the best thing he's done is just be around and be there to support me and stuff like that. (UROP student)*

Senior scientists took a personal interest in students and ensured that they were intellectually engaged with their projects.

> *I think he's always been very, very encouraging and making sure that I'm doing something that I'm interested in, and something that's relevant to me, and… I think he's just done a pretty outstanding job. (UROP student)*

Students also benefited from being taken seriously by senior personnel in the lab. In this way, student felt more socially integrated into the lab group, a necessary prerequisite for intellectual growth and development.

> *I would say they did everything right, especially [the P.I.] because it was good. He never really treated us like we were idiots, which I mean in some ways we are, we just don't know as much as them. Or maybe ignorant might be the right word, we just don't know so much about the subject yet. And he was very helpful because he would explain things very clearly. I thought the way they treated the undergraduates was really good. They made us feel just as important as everybody else. (UROP student)*

Likewise, students benefited from getting to know their P.I.s and advisors "as a person." Students began to see that scientists "are people too."

> *I couldn't have found a better lab. [The P.I.] drives us around in the summer, he'll buy us lunch. It's not like I haven't gotten to know him. I know him really well, and on a personal level. (UROP student)*

Overall, the majority of students reported positive, collegial interactions with their lab groups. Students received valuable personal and emotional support from advisors and peers that helped them to feel comfortable in the lab group. While many UROP students noted that their advisors or P.I.s took an interest in their intellectual and professional development, personal and emotional support was particularly important for BURST students. Some BURST students mentioned that they felt intimidated at the start of their research experience and developing a personal, collegial relationship with senior scientists helped them to feel more comfortable in the lab.

Setting expectations and guidelines

Students made few comments regarding the expectations and guidelines established by their advisors or P.I.s. Nevertheless, it was vital that advisors select projects with achievable goals, set clear expectations for students, and meet regularly with students to assess progress and solve problems. It was also important that students understood how their project contributed to the work of the group. A student recounted the ways in which his P.I. helped to establish clear expectations and short-term and long-term research goals.

He lays it out directly, "These are your responsibilities, these are the trainings that you need to get done before you can start working in our lab, because you're gonna be around this stuff." And then, he puts you on a project, and that project has pretty clear-cut goals on what we're doing on a weekly basis, and over the semester what we're trying to get done. We have weekly meetings so we're always keeping up on exactly who's doing what, and what I'm a part of, and what my goals are, and what their goals are. (UROP student)

Interactions with others in lab

Though all BSI UR students worked in lab groups, students made fewer comments about their lab groups than about their primary advisors or P.I.s. Many students worked side by side with P.I.s or a primary advisor and less closely with others in their lab group. Students in large lab groups—reported by students to include 20, 30, or even 60 to 70 people—often worked one on one with a graduate student or in a smaller group. However, some students, usually those from smaller labs, reported working with the entire lab group. Students' lab groups reflected a variety of sizes. For example, 10% of students reported that they worked in lab groups of over 50 people, 30% in groups of 15-30, 48% in groups of five to 14, and 13% of students worked in small lab groups of fewer than five people.

Students primarily received intellectual support from others in their lab groups. Fully 70% of BURST students' comments about others in their lab group referenced intellectual support, while 41% of UROP students' comments referenced this domain. In contrast, 31% of UROP students but no BURST students' comments referenced professional socialization. UROP students' interactions with others in the lab may have generated greater gains in professional socialization because they were more intellectually and socially integrated into the larger lab group than their novice peers.

Students asked for help from others in the lab when their primary advisors were unavailable.

There's always people in there to ask…. If you don't understand something that's going on, somebody else will know. And so you can pretty much ask anybody in the lab and they can help you understand. (BURST student)

Everyone's really nice and helpful. I can ask anyone for help, they're all available to help me, if [my advisor's] not there or something. Everyone's really nice and friendly (BURST student)

More experienced students turned to their lab group for intellectual support and to discuss research findings.

So every time I get new data, or just basically after every experiment, I kind of talk about it with the people in my lab. And that's a lot of just group brainstorming about what could have happened or what that means. (UROP student)

Students also sought support and guidance from their lab groups. Students enjoyed working with their lab group and looked to their lab-mates for support when their research did not go as planned.

> *It's a pretty fun community to work in, actually. We're usually working on different things, but we understand what the other one is working on. And we can talk about it, or talk about ideas we have, or just complain about it sometimes if it's not going well. (BURST student)*

A few students also mentioned the socialization benefits of interactions with their lab groups. By working closely with graduate students and learning about their educational and career paths, students gained a greater understanding of the career decision-making process of graduate students.

> *I think the most valuable relationships I've formed are with my advisor and the other graduate students, because they're sort of in the same place that I am. They're just a little bit further ahead. They graduated from college, but then they decided to go to graduate school, and now they're trying to decide what they want to do after graduate school. So it's interesting to sort of pick their brains, and see what kinds of things they are thinking about for careers, or what they have done in between undergraduate and graduate schools, to sort of decide what they wanted to do. (BURST student)*

Lab groups occasionally offered critique of students' abstracts or posters. They helped students to develop and design their posters by providing real-life examples of posters for students to use as models.

> *They all helped me, we have a bunch of [posters to be used as models] so they kind of pulled some out and I looked at them to see what worked and what didn't look good and just what kind of information needed to go on it. (UROP student)*

Again, students' comments provide insight into how students are increasingly integrated into a lab group as they become more experienced. Entry-level students needed someone to go to with a question or problem, and to feel that they could contribute to the work of the group. As students advanced as researchers, they became more integrated into the lab group and they began to engage in higher-level discussions with their peers. They also began to gain socialization benefits from their interactions with the larger lab group.

There were only nine negative/mixed comments about interactions among the lab group. One student mentioned that it was difficult to be the only undergraduate in the lab, and the rest of the comments referred to isolation from others, rather than a lack of collegial atmosphere.

> *I'm not sure what kinds of progress other grad students are making on the project, so, I mean I never see them, so I can't really ask them when I'm in the lab. (UROP student)*

In conclusion, most students seem to have been well served by their interactions with their advisors, P.I.s and others in their lab groups. Almost all student comments about mentoring were positive and referenced the ways in which senior scientists supported them. Interactions with their advisors and lab groups provided benefits of socialization into the profession and the discipline, intellectual support on their projects, and personal and emotional support. As students gained experience, what they needed from their advisors changed. Initially, students needed to have their questions answered and to gain basic knowledge and information. Advanced students needed support in generating and modifying experimental design and engaging in critique and oral argumentation. As advanced students became more socially and intellectually integrated into the lab group, they in turn received greater benefits through these collegial, working relationships.

Conclusion and recommendations

Almost all students were highly satisfied with both their research experience and the support provided by BSI programs. Students noted many intellectual, personal, and professional benefits from participation in research. They also felt supported by BSI staff, particularly Lynn Wolfe, and gained insight into scholarly, professional practice through writing workshops and the UROP poster presentation. However, a small fraction of students needed more intellectual challenge in their lab duties and more guidance from senior scientists.

While many students found the BSI workshops to be beneficial learning experiences—or at least a "good refresher" of basic knowledge and laboratory skills—some students, particularly from the UROP program, did not perceive the value or relevance of program workshops. BSI staff should emphasize the learning objectives of each workshop and how these develop the knowledge and skills required of scientists. For students not interested in graduate school or a research career, BSI staff should emphasize that there is evidence that learning from the workshops transfers to courses and non-research careers. For instance, students' gains in laboratory and library skills transferred to their academic coursework, and gains in writing and communication skills will transfer to any professional environment.

Since not all students engaged in bench work during their research experience, the BSI might institute optional workshops in human subjects or animal research for students in other life sciences disciplines. Instead of a single mandatory laboratory workshop, the BSI could offer a series of orientation workshops based on specific research techniques, such as animal subjects, human subjects, preparing solutions and pipetting, etc. In consultation with their advisors, students could select the workshops that are most relevant to their research placement, regardless of their program affiliation with BURST or UROP.

The "value added" of the BURST and UROP programs, beyond simply the research experience itself, is the programmatic emphasis on communication skills. Most students would not have developed scientific writing or presentation skills from their research experience alone. UROP students gained experience and skill in proposal writing and poster presentation, but the BURST program could emphasize writing and presentation to a greater extent. The opportunity to communicate research results in a scholarly forum is an important learning opportunity for novice researchers. The optional participation of BURST students in the UROP poster session is a promising experiment, as posters are often the first form of academic scholarship for novice scientists. Because posters require concise summaries that are conceptually rather than technically focused, they provide an important opportunity for beginning scientists to consolidate their understanding in the "writing-to-learn" tradition, but with a smaller product on which to focus than a full research report.

BSI staff might also consider ways to meet students' desire for a higher level of expert feedback to students on their posters. The poster session can serve as a model of the peer review process and scholarly critique, so the challenge is to optimize the benefits of this activity. Several students mentioned that faculty may not have been aware of the poster session and did not attend in large numbers. Strategies such as advertising the poster session (and its refreshments!) in all participating academic departments—with multiple reminders if necessary; sending personal invitations to P.I.s and advisors of BURST and UROP students; and encouraging lab groups to help prepare their students through a mini-poster session or presentation in their own lab, might help to raise awareness of the event. Attendance by more faculty and postdoctoral researchers could raise the level of scholarly dialogue at the event and serve as a model of professional practice and interaction for students. However, even with optimal use of such strategies, it may be difficult to sustain a high level of faculty attendance over time. Thus it may be even more fruitful to concentrate on raising students' ability to comment on and critique each others' work, by practicing this skill in smaller ways throughout the program workshops. If students presented aspects of their own work and learned from others, they would be more able to contribute this function themselves, less reliant on senior scientists to do it for them, and feel a stronger sense of their own abilities to participate in scientific discourse.

Feedback on the research experience

Nearly all students' comments about their research experience referenced intellectual, personal, and professional gains from participation, and clearly almost all BSI students had a satisfactory and beneficial research experience. A few students, however, had some degree of dissatisfaction with the work they performed or the mentoring they received. These comments were rare, but are instructive for shaping future advisor training and for identifying and intervening with students with poor-quality experiences.

Students' reports of cognitive, personal, and professional gains highlight their progressive learning and development as they gain experience in the lab. Students first developed basic knowledge and understanding, then more advanced problem-solving and data analysis skills. At the highest levels, students interpreted research findings, gained experimental design skills, and evaluated competing arguments. Few students advanced to this high level, but this nonetheless shows the potential for deep intellectual gains from UR when advisors foster such growth. Students' personal gains also reflect a developmental progression; novice students gained general confidence from observing and working closely with senior personnel, while more experienced students gained confidence specifically in their ability to do research. Novice students learned to conduct lab procedures independently, while more experienced students learned to think independently and creatively about their project.

Our prior research and evaluation studies have demonstrated the importance for UR students of engagement in authentic work with adequate guidance and support (Coates et al., 2005; Thiry et al., 2009). Most students in this study engaged in authentic research tasks and responsibilities. They detailed a wide variety of data collection and analysis techniques that they utilized in their research placement, and many also had the opportunity to interpret research findings and plan the next steps in their experiment. However, a few students—primarily from BURST—engaged in "busy work" such as setting up a lab, ordering equipment, and filing invoices. Others never advanced beyond routine data collection methods. To ensure that all students engage in authentic work and face appropriate intellectual challenge, advisor training should emphasize appropriate project selection for novice and advanced students, and stress ways to guide novice students toward greater independence *and* responsibility in the lab.

Students described their interactions with their advisors, P.I.s, and other scientists in the lab as overwhelmingly positive. A few students were not satisfied with these relationships with their advisors and/or P.I.s or had very little interaction with their advisors. Both quality and quantity of time with senior scientists is important to generate personal, professional, and intellectual growth in novice researchers (Coates et al., 2005; Thiry et al., 2009; Thiry & Laursen, 2009).

Students reported that both primary advisors and P.I.s contributed to their intellectual development; however, primary advisors contributed substantially more to students' professional development through their daily interactions. This finding suggests that students are socialized most effectively by close, day-to-day work and interactions with more experienced scientists. Advisor training can stress the importance of these everyday interactions for students' professional development.

In conclusion, BSI UR students were highly satisfied with their research experiences and the level of support they received both from the BSI program and their advisors in the lab. Students discussed many intellectual, personal, and professional gains from their participation in research. Student outcomes from the BSI's UR programs rivaled those of the high-quality research experiences chronicled in our four-college study (Seymour et al., 2004; Hunter et al., 2007). However, a few students had poor placements without adequate challenge or supervision. To address the needs of this minority of students, we recommend that the BSI initiate a mid-semester evaluation or check-in to assess the quality of students' research experiences in terms of their research duties and the quality of mentoring. Additionally, advisor training should emphasize the importance of appropriate project selection, continual guidance of students toward greater levels of independence and responsibility, and integrating students into the social and intellectual life of the research group.

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