Becoming a Scientist: The Role of Undergraduate Research in Students' Cognitive, Personal, and Professional Development

ANNE-BARRIE HUNTER, SANDRA L. LAURSEN, ELAINE SEYMOUR
Ethnography & Evaluation Research, Center to Advance Research and Teaching in the Social Sciences, University of Colorado, Campus Box 580, Boulder, CO 80309, USA

ABSTRACT: In this ethnographic study of summer undergraduate research (UR) experiences at four liberal arts colleges, where faculty and students work collaboratively on a project of mutual interest in an apprenticeship of authentic science research work, analysis of the accounts of faculty and student participants yields comparative insights into the structural elements of this form of UR program and its benefits for students. Comparison of the perspectives of faculty and their students revealed considerable agreement on the nature, range, and extent of students' UR gains. Specific student gains relating to the process of "becoming a scientist" were described and illustrated by both groups. Faculty framed these gains as part of professional socialization into the sciences. In contrast, students emphasized their personal and intellectual development, with little awareness of their socialization into professional practice. Viewing study findings through the lens of social constructivist learning theories demonstrates that the characteristics of these UR programs, how faculty practice UR in these colleges, and students' outcomes—including cognitive and personal growth and the development of a professional identity—strongly exemplify many facets of these theories, particularly, student-centered and situated learning as part of cognitive apprenticeship in a community of practice. © 2006 Wiley Periodicals, Inc. *Sci Ed* **91**:36–74, 2007

INTRODUCTION

In 1998, the Boyer Commission Report challenged United States' research universities to make research-based learning the standard of students' college education. Funding agencies and organizations promoting college science education have also strongly recommended that institutions of higher education provide greater opportunities for authentic, interdisciplinary, and student-centered learning (National Research Council, 1999, 2000, 2003a, 2003b; National Science Foundation [NSF], 2000, 2003a). In line with these recommendations, tremendous resources are expended to provide undergraduates with opportunities to participate in faculty-mentored, hands-on research (e.g., the NSF-sponsored Research Experience for Undergraduates [REU] program, Howard Hughes Medical Institute Science Education Initiatives).

Notwithstanding widespread belief in the value of undergraduate research (UR) for students' education and career development, it is only recently that research and evaluation studies have produced results that begin to throw light on the benefits to students, faculty, or institutions that are generated by UR opportunities (Bauer & Bennett, 2003; Lopatto, 2004a; Russell, 2005; Seymour, Hunter, Laursen, & DeAntoni, 2004; Ward, Bennett, & Bauer, 2002; Zydney, Bennett, Shahid, & Bauer, 2002a, 2002b). Other reports focus on the effects of UR experiences on retention, persistence, and promotion of science career pathways for underrepresented groups (Adhikari & Nolan, 2002; Barlow & Villarejo, 2004; Hathaway, Nagda, & Gregerman, 2002; Nagda et al., 1998). It is encouraging to find strong convergence as to the types of gains reported by these studies (Hunter, Laursen, & Seymour, 2006). However, we note limited or no discussion of some of the stronger gains that we document, such as students' personal and professional growth (Hunter et al., 2006; Seymour et al., 2004) and significant variation in how particular gains (especially intellectual gains) are defined.

Ongoing and current debates in the academic literature concerning how learning occurs, how students develop intellectually and personally during their college years, and how communities of practice encourage these types of growth posit effective practices and the processes of students' cognitive, epistemological, and interpersonal and intrapersonal development. Although a variety of theoretical papers and research studies exploring these topics are widely published, with the exception of a short article for Project Kaleidoscope (Lopatto, 2004b), none has yet focused on intensive, summer apprentice-style UR experiences as a model to investigate the validity of these debates.[1] Findings from this research study to establish the nature and range of benefits from UR experiences in the sciences, and in particular, results from a comparative analysis of faculty and students' perceptions of gains from UR experiences, inform these theoretical discussions and bolster findings from empirical studies in different but related areas (i.e., careers research, workplace learning, graduate training) on student learning, cognitive and personal growth, the development of professional identity, and how communities of practice contribute to these processes.

This article will present findings from our faculty and first-round student data sets that manifest the concepts and theories underpinning constructivist learning, development of professional identity, and how apprentice-style UR experience operates as an effective community of practice. As these bodies of theory are central tenets of current science education reform efforts, empirical evidence that provides clearer understanding of the actual practices and outcomes of these approaches inform national science education policy concerns for institutions of higher learning to increase diversity in science, numbers of students majoring in science, technology, engineering, or mathematics (STEM) disciplines, student retention in undergraduate and graduate STEM programs and their entry

---

[1] David Lopatto was co-P.I. on this study and conducted quantitative survey research on the basis of our qualitative findings at the same four liberal arts colleges.

into science careers, and, ultimately, the production of greater numbers of professional scientists.

To frame discussion of findings from this research, we present a brief review of theory on student learning, communities of practice, and the development of personal and professional identity germane to our data.

CONSTRUCTIVIST LEARNING, COMMUNITIES OF PRACTICE, AND IDENTITY DEVELOPMENT

Apprentice-style UR fits a theoretical model of learning advanced by constructivism, in which learning is a process of integrating new knowledge with prior knowledge such that knowledge is continually constructed and reconstructed by the individual. Vygotsky's social constructivist approach presented the notion of "the zone of proximal development," referencing the potential of students' ability to learn and problem solve beyond their current knowledge level through careful guidance from and collaboration with an adult or group of more able peers (Vygotsky, 1978). According to Green (2005), Vygotsky's learning model moved beyond theories of "staged development" (i.e., Piaget) and "led the way for educators to consider ways of working with others beyond the traditional didactic model" (p. 294). In social constructivism, learning is student centered and "situated." Situated learning, the hallmark of cultural and critical studies education theorists (Freire, 1990; Giroux, 1988; Shor, 1987), takes into account students' own ways of making meaning and frames meaning-making as a negotiated, social, and contextual process. Crucial to student-centered learning is the role of educator as a "facilitator" of learning.

In constructivist pedagogy, the teacher is engaged with the student in a two-way, dialogical sharing of meaning construction based upon an activity of mutual interest. Lave and Wenger (1991) and Wenger (1998) extended tenets of social constructivism into a model of learning built upon "communities of practice." In a community of practice "newcomers" are socialized into the practice of the community (in this case, science research) through mutual engagement with, and direction and support from an "old-timer." Lave and Wenger's development of the concept and practice of this model centers on students' "legitimate peripheral participation." This construct describes the process whereby a novice is slowly, but increasingly, inducted into the knowledge and skills (both overt and tacit) of a particular practice under the guidance and expertise of the master. Legitimate peripheral participation requires that students actively participate in the authentic practice of the community, as this is the process by which the novice moves from the periphery toward full membership in the community (Lave & Wenger, 1991). Similar to Lave and Wenger's communities of practice, Brown, Collins, and Duguid (1989) and Farmer, Buckmaster, and LeGrand (1992) describe "cognitive apprenticeships." A *cognitive apprenticeship* "starts with deliberate instruction by someone who acts as a model; it then proceeds to model-guided trials by practitioners who progressively assume more responsibility for their learning" (Farmer et al., 1992, p. 42). However, these latter authors especially emphasize the importance of students' ongoing opportunities for self-expression and reflective thinking facilitated by an "expert other" as necessary to effective legitimate peripheral participation.

Beyond gains in understanding and exercising the practical and cultural knowledge of a community of practice, Brown et al. (1989) discuss the benefits of cognitive apprenticeship in helping learners to deal capably with ambiguity and uncertainty—a trait particularly relevant to conducting science research. In their view, cognitive apprenticeship "teaches individuals how to think and act satisfactorily in practice. It transmits useful, reliable knowledge based on the consensual agreement of the practitioners, about how to deal with situations, particularly those that are ill-defined, complex and risky. It teaches

'knowledge-in-action' that is 'situated'" (quoted in Farmer et al., 1992, p. 42). Green (2005) points out that Bowden and Marton (1998, 2004) also characterize effective *communities of practice* as teaching skills that prepare apprentices to negotiate undefined "spaces of learning": "the 'expert other'. . . does not necessarily 'know' the answers in a traditional sense, but rather is willing to support collaborative learning focused on the 'unknown future.' In other words, the 'influential other' takes learning. . . to spaces where the journey itself is unknown to everyone" (p. 295). Such conceptions of communities of practice are strikingly apposite to the processes of learning and growth that we have found among UR students, particularly in their understanding of the nature of scientific knowledge and in their capacity to confront the inherent difficulties of science research.

These same issues are central to Baxter Magolda's research on young adult development. The "epistemological reflection" (ER) model developed from her research posits four categories of intellectual development from simplistic to complex thinking: from "absolute knowing" (where students understand knowledge to be certain and view it as residing in an outside authority) to "transitional knowing" (where students believe that some knowledge is less than absolute and focus on finding ways to search for truth), then to "independent knowing" (where students believe that most knowledge is less than absolute and individuals can think for themselves), and lastly to "contextual knowing" (where knowledge is shaped by the context in which it is situated and its veracity is debated according to its context) (Baxter Magolda, 2004).

In this model, epistemological development is closely tied to development of identity. The ER model of "ways of knowing" gradually shifts from an externally directed view of knowing to one that is internally directed. It is this epistemological shift that frames a student's cognitive and personal development—where knowing and sense of self shift from external sources to reliance upon one's own internal assessment of knowing and identity. This process of identity development is referred to as "self-authorship" and is supported by a constructivist-developmental pedagogy based on "validating students as knowers, situating learning in students' experience, and defining learning as mutually constructed meaning" (Baxter Magolda, 1999, p. 26). Baxter Magolda's research provides examples of pedagogical practice that support the development of self-authorship, including learning through scientific inquiry. As in other social constructivist learning models, the teacher as facilitator is crucial to students' cognitive and personal development:

> Helping students make personal sense of the construction of knowledge claims and engaging students in knowledge construction from their own perspectives involves validating the students as knowers and situating learning in the students' own perspectives. Becoming socialized into the ways of knowing of the scientific community and participating in the discipline's collective knowledge creation effort involves mutually constructing meaning. (Baxter Magolda, 1999, p. 105)

Here Baxter Magolda's constructivist-developmental pedagogy converges with Lave and Wenger's communities of practice, but more clearly emphasizes students' development of identity as part of the professional socialization process.

Use of constructivist learning theory and pedagogies, including communities of practice, are plainly evident in the UR model as it is structured and practiced at the four institutions participating in this study, as we describe next. As such, the gains identified by student and faculty research advisors actively engaged in apprentice-style learning and teaching provide a means to test these theories and models and offer the opportunity to examine the processes, whereby these benefits are generated, including students' development of a professional identity.

THE APPRENTICESHIP MODEL FOR UNDERGRADUATE RESEARCH

Effective UR is defined as, "an inquiry or investigation conducted by an undergraduate that makes an original intellectual or creative contribution to the discipline" (NSF, 2003b, p. 9). In the "best practice" of UR, the student draws on the "mentor's expertise and resources. . . and the student is encouraged to take primary responsibility for the project and to provide substantial input into its direction" (American Chemical Society's Committee on Professional Training, quoted in Wenzel, 2003, p. 1). Undergraduate research, as practiced in the four liberal arts colleges in this study, is based upon this apprenticeship model of learning: student researchers work collaboratively with faculty in conducting authentic, original research.

In these colleges, students typically underwent a competitive application process (even when a faculty member directly invited a student to participate). After sorting applications, and ranking students' research preferences, faculty interviewed students to assure a good match between the student's interests and the faculty member's research and also between the faculty member and the student. Generally, once all application materials were reviewed (i.e., students' statements of interest, course transcripts, grade point averages [GPA]), faculty negotiated as a group to distribute successful applicants among the available summer research advisors. Students were paid a stipend for their full-time work with faculty for 10 weeks over summer. Depending on the amount of funding available and individual research needs, faculty research advisors supervised one or more students. Typically, a faculty research advisor worked with two students for the summer, but many worked with three or four, or even larger groups.

In most cases, student researchers were assigned to work on predetermined facets of faculty research projects: each student project was open ended, but defined, so that a student had a reasonable chance of completing it in the short time frame and of producing useful results. Faculty research advisors described the importance of choosing a project appropriate to the student's "level," taking into account their students' interests, knowledge, and abilities and aiming to stretch their capacities, but not beyond students' reach. Research advisors were often willing to integrate students' specific interests into the design of their research projects.

Faculty research advisors described the intensive nature of getting their student researchers "up and running" in the beginning weeks of the program. Orienting students to the laboratory and to the project, providing students with relevant background information and literature, and teaching them the various skills and instrumentation necessary to work effectively required adaptability to meet students at an array of preparation levels, advance planning, and a good deal of their time. Faculty engaged in directing UR discussed their role as facilitators of students' learning. In the beginning weeks of the project, faculty advisors often worked one-on-one with their students. They provided instruction, gave "mini-lectures," explained step by step why and how processes were done in particular ways—all the time modeling how science research is done. When necessary, they closely guided students, but wherever possible, provided latitude for and encouraged students' own initiative and experimentation. As the summer progressed, faculty noted that, based on growing hands-on experience, students gained confidence (to a greater or lesser degree) in their abilities, and gradually and increasingly became self-directed and able, or even eager, to work independently.

Although most faculty research advisors described regular contact with their student researchers, most did not work side by side with their students everyday. Many research advisors held a weekly meeting to review progress, discuss problems, and make sure students (and the projects) were on the right track. At points in the research work, faculty

could focus on other tasks while students worked more independently, and the former were available as necessary. When students encountered problems with the research, faculty would serve as a sounding board while students described their efforts to resolve difficulties. Faculty gave suggestions for methods that students could try themselves, and when problems seemed insurmountable to students, faculty would troubleshoot with them to find a way to move the project forward.

Faculty research advisors working with two or more student researchers often used the research peer group to further their students' development. Some faculty relied on more-senior student researchers to help guide new ones. Having multiple students working in the laboratory (whether or not on the same project) also gave student researchers an extra resource to draw upon when questions arose or they needed help. In some cases, several faculty members (from the same or different departments) scheduled weekly meetings for group discussion of their research projects. Commonly, faculty assigned articles for students to summarize and present to the rest of the group. Toward the end of summer, weekly meetings were often devoted to students' practice of their presentations so that the research advisor and other students could provide constructive criticism. At the end of summer, with few exceptions, student researchers attended a campus-wide UR conference, where they presented posters and shared their research with peers, faculty, and institution administrators.

Undergraduate research programs in these liberal arts colleges also offered a series of seminars and field trips that explored various science careers, discussed the process of choosing and applying to graduate schools, and other topics that focused on students' professional development.

We thus found that, at these four liberal arts colleges, the practice of UR embodies the principles of the apprenticeship model of learning where students engage in active, hands-on experience of doing science research in collaboration with and under the auspices of a faculty research advisor.

RESEARCH DESIGN

This qualitative study was designed to address fundamental questions about the benefits (and costs) of undergraduate engagement in faculty-mentored, authentic research undertaken outside of class work, about which the existing literature offers few findings and many untested hypotheses.[2] Longitudinal and comparative, this study explores:

- what students identify as the benefits of UR—both following the experience, and in the longer term (particularly career outcomes);
- what gains faculty advisors observe in their student researchers and how their view of gains converges with or diverges from those of their students;
- the benefits and costs to faculty of their engagement in UR;
- what, if anything, is lost by students who do not participate in UR; and
- the processes by which gains to students are generated.

This study was undertaken at four liberal arts colleges with a strong history of UR. All four offer UR in three core sciences—physics, chemistry, and biology—with additional programs in other STEM fields, including (at different campuses) computer science, engineering, biochemistry, mathematics, and psychology. In the apprenticeship model of UR practiced at these colleges, faculty alone directed students in research; however, in the few

[2] An extensive review and discussion of the literature on UR is presented in Seymour et al. (2004).

instances where faculty conducted research at a nearby institution, some students did have contact with post docs, graduate students, or senior laboratory technicians who assisted in the research as well.

We interviewed a cohort of (largely) "rising seniors" who were engaged in UR in summer 2000 on the four campuses ($N = 76$). They were interviewed for a second time shortly before their graduation in spring 2001 ($N = 69$), and a third time as graduates in 2003–2004 ($N = 55$). The faculty advisors ($N = 55$) working with this cohort of students were also interviewed in summer 2000, as were nine administrators with long experience of UR programs at their schools.

We also interviewed a comparison group of students ($N = 62$) who had not done UR. They were interviewed as graduating seniors in spring 2001, and again as graduates in 2003–2004 ($N = 25$). A comparison group ($N = 16$) of faculty who did not conduct UR in summer 2000 was also interviewed.

Interview protocols focused upon the nature, value, and career consequences of UR experiences, and the methods by which these were achieved.[3] After classifying the range of benefits claimed in the literature, we constructed a "gains" checklist to discuss with all participants "what faculty think students may gain from undergraduate research." During the interview, UR students were asked to describe the gains from their research experience (or by other means). If, toward the end of the interview, a student had not mentioned a gain identified on our "checklist," the student was queried as to whether he or she could claim to have gained the benefit and was invited to add further comment. Students also mentioned gains they had made that were not included in the list. With slight alterations in the protocol, we invited comments on the same list of possible gains from students who had not experienced UR, and solicited information about gains from other types of experience. All students were asked to expand on their answers, to highlight gains most significant to them, and to describe the sources of any benefits.

In the second set of interviews, the same students (nearing graduation) were asked to reflect back on their research experiences as undergraduates, and to comment on the relative importance of their research-derived gains, both for the careers they planned and for other aspects of their lives. In the final set of interviews, they were asked to offer a retrospective summary of the origins of their career plans and the role that UR and other factors had played in them, and to comment on the longer term effects of their UR experiences—especially the consequences for their career choices and progress, including their current educational or professional engagement. Again, the sources of gains cited were explored; especially gains that were identified by some students as arising from UR experiences but may also arise from other aspects of their college education.

The total of 367 interviews represents more than 13,000 pages of text data. We are currently analyzing other aspects of the data and will report findings on additional topics, including the benefits and costs to faculty of their participation in UR and longitudinal and comparative outcomes of students' career choices. This article discusses findings from a comparative analysis of all faculty and administrator interviews ($N = 80$), with findings from the first-round UR student interviews ($N = 76$), and provides empirical evidence of the role of UR experiences in encouraging the intellectual, personal, and professional development of student researchers, and how the apprenticeship model fits theoretical discussions on these topics.

---

[3] The protocol is available by request to the authors via abhunter@colorado.edu.

METHODS OF DATA TRANSCRIPTION, CODING, AND ANALYSIS

Our methods of data collection and analysis are ethnographic, rooted in theoretical work and methodological traditions from sociology, anthropology, and social psychology (Berger & Luckman, 1967; Blumer, 1969; Garfinkel, 1967; Mead, 1934; Schutz & Luckman, 1974). Classically, qualitative studies such as ethnographies precede survey or experimental work, particularly where existing knowledge is limited, because these methods of research can uncover and explore issues that shape informants' thinking and actions. Good qualitative software computer programs are now available that allow for the multiple, overlapping, and nested coding of a large volume of text data to a high degree of complexity, thus enabling ethnographers to disentangle patterns in large data sets and to report findings using descriptive statistics. Although conditions for statistical significance are rarely met, the results from analysis of text data gathered by careful sampling and consistency in data coding can be very powerful.

Interviews took between 60 and 90 minutes. Taped interviews and focus groups were transcribed verbatim into a word-processing program and submitted to "The Ethnograph," a qualitative computer software program (Seidel, 1998). Each transcript was searched for information bearing upon the research questions.

In this type of analysis, text segments referencing issues of different type are tagged by code names. Codes are not preconceived, but empirical: each new code references a discrete idea not previously raised. Interviewees also offer information in spontaneous narratives and examples, and may make several points in the same passage, each of which is separately coded. As transcripts are coded, both the codes and their associated passages are entered into "The Ethnograph," creating a data set for each interview group (eight, in this study). Code words and their definitions are concurrently collected in a codebook. Groups of codes that cluster around particular themes are assigned and grouped by "parent" codes. Because an idea that is encapsulated by a code may relate to more than one theme, code words are often assigned multiple parent codes. Thus, a branching and interconnected structure of codes and parents emerges from the text data, which, at any point in time, represents the state of the analysis.

As information is commonly embedded in speakers' accounts of their experience rather than offered in abstract statements, transcripts can be checked for internal consistency; that is, between the opinions or explanations offered by informants, their descriptions of events, and the reflections and feelings these evoke. Ongoing discussions between members of our research group continually reviewed the types of observations arising from the data sets to assess and refine category definitions and assure content validity.

The clustered codes and parents and their relationships define themes of the qualitative analysis. In addition, frequency of use can be counted for codes across a data set, and for important subsets (e.g., gender), using conservative counting conventions that are designed to avoid overestimation of the weight of particular opinions. Together, these frequencies describe the relative weighting of issues in participants' collective report. As they are drawn from targeted, intentional samples, rather than from random samples, these frequencies are not subjected to tests for statistical significance. They hypothesize the strength of particular variables and their relationships that may later be tested by random sample surveys or by other means. However, the findings in this study are unusually strong because of near-complete participation by members of each group under study.

Before presenting findings from this study, we provide an overview of the results of our comparative analysis and describe the evolution of our analysis of the student interview data as a result of emergent findings from analysis of the faculty interview data.

OVERVIEW OF FINDINGS FROM THE FIRST-ROUND STUDENT INTERVIEWS AND OF ALL FACULTY INTERVIEW DATA AND REEVALUATION OF THE STUDENT-IDENTIFIED GAINS CATEGORIES

Students' evaluative observations on their UR experience were overwhelmingly positive: 91% of all statements referenced gains from their summer research experience. Few negative, ambivalent, or qualified assessments of their research experiences were offered. The benefits described were of seven different kinds. Expressed as percentages of all reported gains, they were: personal-professional gains (28%); "thinking and working like a scientist" (28%); gains in various skills (19%); clarification/confirmation of career plans (including graduate school) (12%); enhanced career/graduate school preparation (9%); shifts in attitudes to learning and working as a researcher (4%); other benefits (1%) (Seymour et al., 2004).

Like students, faculty regarded UR experience as highly beneficial: 90% of all faculty members' evaluative observations discussed students' gains. Faculty offered observations that drew on their long experience of directing UR. They reported not just gains for their current research group but also gains that they had observed in student researchers collectively, over time, including examples of individual, outstanding students. Faculty members' observations also reflected their perspective as educators and as professional scientists. Faculty noted gains that students mentioned, but framed them in terms of students' growth as young professionals, especially development of attitudes and behaviors viewed as requisite for students to continue in science research, and ultimately, replace the profession. We called this emergent category "becoming a scientist." "Becoming a scientist" was the only new category of gains identified from the faculty interview data; other gains categories were comparable to those derived from original analysis of the student interviews. Thus, benefits to students of UR experiences identified by faculty were "thinking and working like a scientist" (23%), "becoming a scientist" (20%), personal-professional gains (19%), clarification/confirmation of career plans (including graduate school) (16%), enhanced career/graduate school preparation (10%), gains in various skills (8%), and other benefits (4%).

Discovery of the emergent "becoming a scientist" category sent us back to reexamine the student data. In line with qualitative methodology, we reviewed these data to better understand and guide our developing interpretations of the findings (Strauss, 1987). According to Bowden and Marton's (1998) variation theory, it is precisely by examining the differences or contrasting nature of the data that researchers are better able to discern the issues and patterns being studied.

In the process of comparing faculty and students' responses, it became evident that their observations reflected particular points of view: faculty and students addressed the same types of gains, but interpreted certain gains differently. Students were interviewed immediately following their summer research experience, just prior to their senior year of college, and, from their responses, it is clear that many were still uncertain about future plans. Students emphasized the benefits of UR experience as contributing to their personal growth and understanding of how science works in hands-on practice. As noted above, faculty members' observations were framed by their long professional experience. They described much of students' growth in terms of their progress in becoming young professionals.

In looking at student gains categories in light of their faculty advisors' perspective, we realized that "becoming a scientist" captured a number of student responses that had been distributed across several gains categories. We therefore re-sorted the student gains

categories to see how they would match faculty definitions.[4] After re-categorizing relevant student-identified UR gains, faculty and students' observations were found to address the same range of benefits, though both groups offered a small number of observations that were not directly comparable. Table 1 compares faculty and students' observations on gains from UR after reevaluating the student gains categories based on faculty advisors' broader professional perspective on students' personal growth. Numbers and percentages of students' observations on gains from UR that are presented in this table replace those given in Table 2 in Seymour et al. (2004).

The results of this study show that faculty and students' observations address the same range of benefits. However, what is clear from our comparative analysis of the interview data is that faculty and students frame student gains differently. Students themselves were (as yet) unaware of the significance of gains in professional socialization that their faculty advisors have observed in many students over time as a result of engaging in authentic research. In their roles as research advisors, mentors, and professional scientists, faculty members see students' gains from UR as developmental stepping stones important to the process of students "becoming scientists."

We now turn to a discussion of the positive outcomes, as both the student researchers and their faculty research advisors variously perceive them. As indicated in the summary of student gains provided in Table 1, we have clustered gains reported by faculty members and their student researchers into conceptually distinct categories. After our discussion of the six major student gains categories, we will explore ways in which student benefits from their UR experience relate to the theoretical models of social constructivist student learning, personal and professional identity development in young adults, and communities of practice that we have proposed as an explanatory framework for the faculty's practice of UR in these colleges.

FACULTY AND STUDENTS' OBSERVATIONS ON GAINS FROM UR EXPERIENCE IN THE SCIENCES

In this section, we present findings for each of the six major categories of student gains identified in our comparative analysis of faculty and student interview data. Throughout the discussion, we illustrate (sometimes different) ways in which faculty and their students view particular areas of gain and their significance.

"Thinking and Working Like a Scientist"

Gains in the "thinking and working like a scientist" category describe growth in students' intellectual and practical understanding of how science research is done, including critical thinking and problem-solving skills, understanding the nature of scientific knowledge, as well as deeper conceptual understanding of science and connections between the different disciplines. In this category, we note in students' observations a process that is encouraged by active engagement in research: many students improve their ability to bring their knowledge, critical thinking, and problem-solving skills to bear on real research questions; a few students go further, gaining insights into how to generate and frame research problems so that they can be approached scientifically; and some develop a clearer understanding of how knowledge is constructed by seeing the implications of their research design choices for the certainty of the answers thus generated.

---

[4] For a detailed description of how student gains were re-categorized, see Hunter et al. (2006).

TABLE 1
Comparison of Faculty and Students' Observations on Gains from Undergraduate Research

"Parent" Categories: Grouping of Gain-related Codes	Observed Gain, N (%)	
	Faculty	Student
Thinking and working like a scientist		
Application of knowledge and skills: understanding science research through hands-on experience (gains in critical thinking/problem solving, analyzing, and interpreting results); understanding the nature of scientific knowledge (open ended, constantly constructed); understanding how to approach research problems/design. Increased *knowledge and understanding of science and research work* (theory, concepts, connections between/within sciences). Transfer between research and courses; increased relevance of coursework.	527 (23)	294 (24)
Becoming a scientist		
Demonstrated gains in behaviors and attitudes necessary to becoming a researcher (student takes "ownership" of project; shows responsibility, intellectual engagement, initiative; creative and independent approach in decision making). Greater understanding of the nature of research work and professional practice. Identification with and bonding to science.	450 (20)	150 (12)
Personal-professional		
Increased confidence in ability to do research, contribute to science, present/defend research, and in "feeling like a scientist." Establishing collegial, working relationships with faculty advisor and peers.	420 (19)	310 (25)
Clarification, confirmation, and refinement of career/education paths		
Increased interest/enthusiasm for field; validation of disciplinary interests and clarification of graduate school intentions (including increased likelihood of going to graduate school); greater knowledge of career/education options; clarification of which field to study; introduced to new field of study.	352 (16)	131 (11)
Enhanced career/graduate school preparation		
Real-world work experience (students); good graduate school/job preparation (faculty); opportunities for collaboration/networking with faculty, peers, other scientists; new professional experiences; résumé enhanced.	228 (10)	120 (10)
Skills		
Communication skills: presentation/oral argument; some writing/editing; laboratory/field techniques; work organization; computer; reading comprehension; working collaboratively; information retrieval.	174 (8)	214 (17)
Generalized and other gains		
"Students learn a lot"; good summer job, access to good laboratory equipment, etc.	84 (4)	7 (1)
Working independently		
Described as a skill, *not* linked to professional practice.	8 ($<$1)	4 ($<$1)
Total	2243 (100)	1230 (100)

This category represents the largest group of faculty-identified student gains, and the second largest set of observations on gains offered by students (Table 1). Each group observed similar intellectual gains from UR. The intellectual gains described in this category are divided broadly into two types: gains in the *application* of their science knowledge to their hands-on research work (86% of faculty observations and 58% of students'), and gains in depth of knowledge and understanding of aspects of their disciplines (15% of faculty observations and 26% of students').

The highest number of observations offered by faculty (42%) and students (24%) in this first major subset of intellectual gains described the application of students' learning to authentic research and how hands-on engagement generated in students an enhanced intellectual and practical understanding of the processes of science research in a context unavailable in traditional coursework or class laboratories:

> If science is a way of knowing, and a particular mechanism for acquiring information by experimentation, as a way to extract information from the world, then [students] certainly see how that's done much more clearly in the summer experience than they would simply reading a textbook or taking part in a canned lab. I don't think there's any doubt that they get a better feel for how science is actually done. (Advisor)

> It's certainly very different from how it's taught. . . . It was definitely in doing research that I learned how science is done. . . . I've gained an experience of what doing science is really like, and doing it professionally in the sense of what it's really like to take data when you don't know what the answer's going to be beforehand, like in a laboratory course. And to test it against a model where you're not sure if you've accounted for everything and to really [learn]. . . what's acceptable for publication. . . . It's one thing to study science, but it's another to work on and solve problems. (Student)

According to observations offered by faculty (25%) and students (22%), many students also grew in their ability to successfully apply critical thinking and problem-solving skills to the work at hand, including the capacity to analyze data in relation to scientific concepts and theories framing research:

> I tend to go around saying, "Okay. What have you done? What is your analysis?" I can tell that they're catching on when, as I start discussing possible interpretations with them and I'll say something and they'll say, "Oh, but that doesn't fit with what we did yesterday." Then you know the science is there. (Advisor)

> One of the more rewarding things, I think, was I took massive loads of data, and there's just tables and tables of data and you're working it up. . . and [my advisor] gives me this little mathematical approach saying, "If you work it this way, it'll work out and give you this." And I was skeptical and I was thinking, "Sure. Sure.". . . And working this data for days and days, just processing this data, sure enough, it kinda culminates to one thing. And I think to see that experimental side work to some sort of mathematical application or theoretical side, I was just kind of amazed by it. (Student)

Although most students discussed both learning about how science research is done and their related experience of gains in applying their critical thinking and problem-solving skills to research, fewer students developed a more complex epistemological understanding of the open-ended nature of scientific knowledge and that scientific "fact" may be subject to revision. Seventeen percent of faculty observations in this category, and only 3% of students' observations, mentioned this type of gain. Nonetheless, a number of faculty and

students' observations in this category indicate that some students do acquire greater insight into how scientific knowledge is built:

> They learn to look at science differently than the way they had it presented in class and the book. . . . There's a little bit of that, "Gosh, I thought everything we know is in this book!" And so they suddenly realize that there's so much that we don't know and that what's in a textbook may be just a guess. (Advisor)

> I've made some great realizations. . . . I think a lot of people think science is truth, this all-encompassing certainty. . . . And what I found out is that often what research does is just to explain how something could happen or probably happens, and not necessarily how it does happen. So I think that has helped me a lot in understanding science better. (Student)

Even fewer faculty members (2%) observed that their students gained a capacity to identify, frame, and refine new research questions or to select or develop alternative experimental designs to test a hypothesis. Students estimated their progress in this regard at a slightly higher level (9%). When discussing this higher level of thinking skills applied to research, faculty often added that most undergraduates were unlikely to develop this level of conceptual understanding and skills; rather, they expected these abilities to develop during graduate school. Additional constraints on the development of thinking skills for this higher level may reflect the dominant tendency in all four colleges for faculty to assign students work on aspects of their existing projects, and the difficulty of achieving such an objective in 10 weeks of summer research.

Our finding is thus, that although most students developed the capacity to usefully apply their scientific understanding to their research projects, few developed either the capacity to generate and frame research questions such that they can be approached by alternative scientific methods or a complex epistemological understanding of science. Descriptions of the state that they had reached in this process were offered by 64 of the 76 students: 46% of students' evaluative comments explained gains in understanding how science research is done and in applying their critical thinking and problem-solving skills to research; 9% referenced gains in their ability to develop a research question and design; and only 3% mentioned growth in understanding how scientific knowledge is built. This finding is important in light of the many claims for higher order thinking found in descriptive accounts of UR experience commonly authored by faculty.

However, we know of only two U.S. studies that carefully probed for and assessed students' higher-order intellectual gains from UR experience. Findings reported are similar to ours. In an evaluation study on gains from UR experiences, Kardash (2000) found only modest gains in "higher-order skills," particularly development of insights into how to generate and frame research problems so they can be approached scientifically. Kardash's conclusions reflect the findings of this study, namely that, although undergraduate research experiences (UREs) "are clearly successful in enhancing a number of basic scientific skills, the evidence is less compelling that UREs are particularly successful in promoting the acquisition of higher-order inquiry skills that underlie the foundation of critical, scientific thinking" (p. 196). In reporting on students' epistemological development, Rauckhorst's (2001) presentation described student transitions in their ways of knowing using Baxter Magolda's ER model. The most commonly found change in students' ways of knowing was from "transitional knowing" to "independent knowing." None of the students in Rauckhorst's study gained the highest level in the ER model, "contextual knowing." Thus, although active participation in UR offers the potential for students to move through a sequence of intellectual gains—from application to design to abstraction—research findings to date concur that this process is neither easy nor guaranteed.

Findings in the second major subset of intellectual gains noted increases in conceptual understanding, deepening of disciplinary knowledge, and an increased understanding of the connections within and between the sciences (13% of faculty observations and 16% of students'). Faculty saw students' increased comprehension of science and their ability to make conceptual and theoretical connections within their research:

> My students presented their work last Tuesday. . . . I wasn't sure that they really understood the point of what we were doing in the experiments. One of my colleagues asked a question of the young woman. . . and she answered it brilliantly. She really had put together bits and pieces that we'd talked about and what the significance of this is. . . . I was so pleased because, intellectually, she has put all these things together and she's synthesizing what she's doing in respect to some of the things that have been done, and are being done.

Some students felt that they had gained a more holistic knowledge of their discipline, whereas others expressed greater learning in terms of depth and detail:

> Well, intellectually I think that it's helped me to understand chemistry better. Not just the chemistry that I happen to be doing in the lab, but also chemistry as a whole, just because my research does relate to many different areas of chemistry. And learning how to look through the primary literature and to really synthesize and understand the information about the project has helped me to better understand other areas of chemistry and pick things up more quickly.

> Just from being out in the field and asking (my advisor), "What's that plant there?" I've gotten a lot more knowledge of the basics. I think you do end up learning techniques or, you know, everything you ever wanted to know about milkweeds!

To summarize, in this category of gains, faculty and students described the intellectual gains derived from UR experience. Dominant for both groups was the benefit of learning how science research is done. Faculty and students also emphasized gains in the application of knowledge and skills to hands-on research, as well as deeper knowledge and understanding of conceptual connections between sciences. Fewer observations were offered on student gains in higher-order thinking skills: identifying a research question and proposing experimental design or developing a more complex understanding of the nature of scientific knowledge.

"Becoming a Scientist"

The "becoming a scientist" category contains faculty and students' observations that reference attributes of professional practice, attitudes, temperament, and identity that faculty see as necessary for emerging scientists. These include:

- demonstrating attitudes and behaviors needed to practice science;
- understanding the nature of research work;
- understanding how scientists practice their profession; and
- beginning to see themselves as scientists.

The high number of faculty's observations documenting students' development as young research professionals (20% of all faculty-identified gains) is especially interesting, not

least because this topic is not yet well represented in the literature.[5] It is also an interesting finding that students who described the same gains did not couch them in terms of the process of "becoming scientists," but largely as aspects of their personal-professional (or other forms of) growth. Once the re-categorization of student observations that matched those of faculty was complete, the resulting category, at 12%, ranked fourth in gains reported by students (Table 1).

Within this category, more than half of faculty observations (52%) described changes they observed in students' conduct and manner, noting how students began to exhibit behaviors and attitudes that underpin research work, such as curiosity and initiative, becoming less fearful of "being wrong," and more willing to take risks:

> They approach me and say, "I know you always say I should at least run it by you before I use expensive reagents, but I did this on my own and look what I got!" And there have been a few that have sort of just done it—around the sides, without letting you know because they wanted to surprise you. That's a real transition point. That they want to surprise you by bringing something of themselves to it. And when you see that happen, you think, "Okay, we're all set here."

> One of the things that pleases me in a student is one who isn't afraid to get in there and just get their hands dirty, and just try something. That's what [he] did. He wasn't worried about wasting some reagents, some enzyme or something. . . . Just to try something to get it to work. Whereas I've had other students who, if it doesn't work, the first thing they do is come to me. . . . [He] got stumped a couple of times. He needed, initially, to be shown how to go about trouble-shooting. But the successful students are the ones that will just get in there and they'll try things on their own and get 'em to work.

Faculty described these shifts in attitudes and behaviors as "transformations" that indicated to them that their students were becoming science professionals.

One quarter of student comments in this category referenced a parallel set of changes in their own behavior and attitudes that they did not, as yet, recognize as acquiring professional habits of mind and behavior. Students described learning to work and think independently, being willing to try something on their own, taking responsibility for their own learning, and figuring things out for themselves (and with their research peer group) rather than relying on faculty. Students also saw themselves becoming increasingly careful in their project work, mindful of their role in providing accurate results, and above all, feeling a sense of ownership and responsibility for the project and its progress:

> Just being able to sit down and concentrate on one thing and figure it out and understand. . . . And so just for me to look at that and really, really understand it rather than just getting the big overview. And then, actually thinking about the problem critically and creatively and being, "Okay. Now what can I change to have this effect and to have this outcome?" That's a whole new experience for me.

---

[5] This gain is proposed, but not documented, in a small number of articles. Gueldner, Clayton, Bramlett, & Boettcher (1993) mention professional socialization as an objective of UR; Dunn and Phillips (1998) and Nikolova Eddins, Williams, Buschek, Porter, & Kineke (1997) discuss as a hypothesized benefit of UR the role of peer interaction and peer assessment as a means of professional socialization. Jungck, Harris, Mercuri, & Tusin (2004) argue that peer review and publication of student research is an important element of students' professional socialization. As noted earlier, Lopatto (2004b) discusses the links between student learning in college and the contribution of UR to students' professional development as scientists.

> I'm being relied on to a certain extent. So if I'm not at least doing the 40 hours. . . , not that I couldn't necessarily slip around it, but I feel that I should at least be in here working for 40 hours. There also is simply the deadline that it has to be published and the end of the 10 weeks is coming up. . . . I mean, there's sort of this contractual obligation. It's sort of a personal obligation I feel. I think that's more important. And so I'm willing to get it done.

Faculty members know that by engaging in authentic research projects, students will come to better understand the character of research work: that it is messy and slow, that it is often boring and tedious, that it may be necessary to repeat a procedure multiple times before it works properly, and that "failure" is a common experience. Nearly one quarter of faculty observations on "becoming a scientist" discussed student gains in understanding the realities of research work. Faculty also saw in students a growing consciousness that to succeed as a scientist requires particular temperamental attributes—whether natural or acquired:

> They learn in the lab that science is an awful lot of frustration. They learn that it's not going to work a lot of the times. So this is one of their lessons that they come out with (laughs). So they get accustomed to the idea that things don't work and they have to figure it out.

> I think they learn that science is really boring (laughs). And that's the key. If they can know that science is boring and still do it, and still stick with it, then they have the makings of a really good scientist.

A small number of students' observations (13%) similarly described gains in understanding of the character of research work and the realization that doing research requires perseverance:

> It's helped me to deal with failure in the laboratory. And it's not your fault. It's not anything you could have done. It's just the protocols that worked perfectly for so-and-so don't work for you because of reasons you didn't even think about and *nobody* thought about. It's helped me to be a better problem-solver, I think, to look at this and say, "Okay, we'll pinpoint what's going wrong. We'll see what other people have done. We'll see why ours is different and how we can change things so that it will work."

Coming to an honest understanding of what real research entails—both its nature and the recognition that one must be able to take its frustrations in stride—is a gain hard won from experience.

Learning that research is typically fraught with problems, that a high incidence of "failure" is to be expected, and that it requires patience and tenacity was also seen by both faculty and students as applicable to life, in general:

> Life in the lab is tough. . . . I've spent years on some projects and not gotten a really great result out of it. And so students will spend a whole semester working on something and have to deal with, "It didn't work this time. Didn't work this time. Didn't work this time." And it's not because it's a bad project. It's because they're in that trouble-shooting phase that you must go through. You can't just buy a kit to do this experiment. You have to just trouble-shoot yourself. And you *have* to go through that in order to get beyond it. And I would say that maturity of, "Things don't always go the way I think they're going to go," is actually a very good life lesson to learn. (Advisor)

> I think the perseverance that it takes, the patience to be able to just keep working and not giving up on things, that is something that I think will be useful in other areas—learning to not expect things to happen right away, and suddenly, magically you have all your results. (Student)

Fifteen percent of faculty observations, but just 5% of students' observations, in "becoming a scientist" mentioned gains in understanding how scientists practice their profession. Faculty advisors were aware that UR provided students with an opportunity to witness first-hand how scientists operate as professionals. Students see that faculty must write papers, undergo peer review and publish, attend conferences, and present papers. Faculty observations in this category identify students' growth in understanding how scientists practice their profession:

> They assist with things like literature searches. . . . I'll frame it in terms of a publication. "This is the kind of stuff we'll need to document in order to publish this." So they get insight into that part of the process. . . . In terms of what the standards are, the way they need to document their experimental work, the kinds of analyses they need. They understand we need one set of data to decide for ourselves, "Oh, we did it!" Now we need another set to tell the world that we did this. So they get insight into those aspects.

Yet, students' observations relating to a growing understanding of standards in professional practice were framed almost entirely in personal terms—as leading to increased confidence and "feeling like scientists." Thus, although students may, indeed, be seeing "how" scientists practice their profession, they largely internalize these gains, focusing on the immediate effects on their own self-development rather than defining them (as do faculty) as habits of the profession.

However, presenting at disciplinary conferences commonly stimulated students to express a clear awareness of the insights they had gained by the experience into how the science profession operates. Students who had been to a conference typically emphasized how this had broadened their understanding of professional practice. They had seen first-hand how big the world of science is; some imagined what a career in science would be like; and some expressed an early sense of belonging to the profession. They also became aware that their research contributions had value to other scientists:

> Especially when I went to the [conference], it gives you an idea of where you might be working and if you would be interested in doing something like that, if you would like it, and types of problems that they have to deal with. It gives you an idea of where you are going to be at a certain point.

> I thought it was a great experience, seeing other people and then really talking to scientists. And I felt like I was really a part of everything because I had my own work that I could share, and I understood so much more about what people were doing because I've written my own abstracts, I've written my own sections of papers. . . . It seems like a really big deal, but in the scientific world, it's kind of like you *need* to see these people. . . .

Faculty members emphasized the added value for students of getting to see how scientists worked beyond the walls of academe. They were aware that attending conferences helped students to see what a future in science might look like, encouraged students to view themselves as part of the scientific community, and, thus held the potential to draw students into its fold:

When they get to the American Chemical Society meeting, they begin to realize that it's a whole lot bigger. . . and they've got connections to people who are out there. . . specific connections that show them the path of how they *can* get there.

I take students to the neuroscience meeting. . . which I think is. . . very good for them because they see what they are learning and doing has a place and a relevancy in the entire scientific community and it's not just they're doing some small piece. . . that is designed for undergraduates. When they go and make these presentations to the scientific community, they realize that they're creating science. They're not just doing formulas in a cookbook, but they're actually now part of the creation of knowledge.

In only a small proportion of students' observations was it clear that students had come to understand the significance of their more testing research experiences as part of a process of socialization into the profession of science. In the following examples, the speakers discuss how they had come to a more practical understanding of the demands of professional science and what this meant in terms of becoming a scientist:

The summer's research was sort of the first step in becoming a true biologist. The nature of the research is such that there are long periods of waiting before we can obtain data. And so some days were particularly trying, but as a whole, I look back on it fondly. I feel like I'm really learning what it's like to be a scientist.

When I really realized some of the frustrations you can have with research, I think I learned that that's a part of being a scientist, is dealing with that.

Most students' observations on "becoming a scientist" (57%) referenced increases in confidence. The results of increased confidence to do science are expressed in students' accounts that show both tacit and unconscious development of traits, behaviors, and attitudes that are part of their development as young scientists. They are part of "becoming scientists" and, as such, are included in this category. Students' statements that express growth in their confidence to take part in science and make some contribution to it were placed in the "personal-professional gains" category because these observations reflect overt, conscious statements of personal growth. Often, however, statements of greater confidence and about the significance or outcomes of greater confidence are intertwined in the same sentence or account. Thus, the "confidence" elements in such statements properly belong in the "personal-professional growth" category and elements expressing growth in feeling and acting like a scientist belong in the "becoming" category. As we explained earlier, the "becoming a scientist" category emerged from our analysis of the faculty interview data. Faculty observations made explicit some aspects of students' development of which students were largely unaware. For students, "feeling like a scientist" was framed entirely in the context of growth in confidence; it was not projected as conscious development of "becoming a scientist." Because the two types of sentiments are highly related, they were counted as gains in both categories. However, as students discussed gains in confidence in terms of their personal development, we will elaborate on the growth of professional identity in our discussion of the "personal-professional gains" category.

In sum, in the "becoming a scientist" category, faculty's observations concern students' development as apprentice scientists. Their observations describe the development of attitudes and behaviors that characterize aptitude for the profession and the adoption of the professional norms necessary for participation in the community of practice. Students' discussion of these types of gains referenced changes in their attitudes and behaviors in

relation to research work; they did not frame their discussion of these gains in terms of professional development. Rather, as we will discuss next, students internalized these gains in terms of their own self-development.

Personal-Professional Gains

The largest number of all student observations on their gains comprises the "personal-professional gains" category, though "thinking and working like a scientist" was a close second. Students' personal-professional gains ranked third in number of faculty's evaluative observations (Table 1). By far, the largest proportion of student comments in this category reference gains in confidence in doing research work or "science" (74%). And although faculty noted these same gains for students (43%), they emphasized more than students a second type of personal-professional gain, namely, the benefits of developing a collegial relationship with faculty. Students' observations on developing collegial, working relationships with faculty strongly reflect their personal significance to students: being treated as a colleague in an equal partnership—"being taken seriously." These experiences encouraged students' confidence both as young adults and as young scientists. Both faculty and students' observations on gaining professional collegiality with faculty (and also with research peers) speak to the structure and function of mentoring and peer group learning in the social practice of the scientific community and in the development and support of professional identity.

Growth in confidence was portrayed as having a number of different facets. Growth in students' confidence to do research often included a shift toward thinking and working independently. It sometimes included gains in technical know-how that fueled feelings of confidence to tackle whatever new learning might be required:

> I've learned not to be so intimidated by the research because, before, when we would read these articles for class, it just seems a bit intimidating. But now that I'm actually doing what they're doing, I've realized that I could do this.

> I now feel confident that I can walk into any room with any instrument and figure out how to make that instrument work. And that's a very nice confidence to have because it makes me feel a lot more optimistic when I look at somebody's web page and what kind of analytical methods they use in the lab. And I see this laundry list of 10, 15 different methods of analysis they're using, and I can look down that list and say, "I know how to do half of these, and another half of them I can figure out pretty easily, based on things I've done."

Faculty advisors affirmed the strong affective gains that students took away from their research experience. A third of the faculty's observations in this category specifically noted increases in students' confidence that made them willing to take on technical challenges and think creatively about alternative ways to approach a research question:

> You can see it a mile away. When they approach a new piece of equipment, it's more, "Well, where's the manual?" (Laughs.) "Don't waste my time teaching me this. Just tell me how to turn it on and I'll figure it out." Self-confidence, maturity.

> I saw him able to approach problems with a little bit more creativity. With a little bit less, "It has to be done precisely one way." I really think he'd gained confidence.

The most powerful source of students' growing confidence as researchers was the realization that their work could make a useful contribution to the field:

> It makes me feel important. I feel like I'm actually contributing something, and it's so exciting!

> Contributing to the field is important. . . . I really like the idea that I am doing science research and I feel like it's something that's new and exciting and it's been looked at sort of, but not really, the research that I'm doing. I get a lot of satisfaction out of the fact that I'm doing something new.

Faculty advisors concurred with their students that a major source of their increased confidence was the awareness that they were able to make a contribution:

> I think when they see what they're doing connects with other people's work. . . that kind of validates a lot of what they do, so I think they like that. This summer we had a lot of requests for the clone that we've isolated. . . and I could see this one student was getting really excited.

Both students and faculty described gains arising from attending and presenting at conferences, although faculty interpreted the significance of these gains in terms of bringing new talent into their profession, students saw these benefits in terms of personal growth with transferable professional value. Students related how preparing and presenting their research and being taken seriously by researchers in the field both increased their confidence as young scientists and enhanced their identification with the profession:

> When you finish your research for the summer and you present your research, you put it in poster form. . . I mean, there's a certain amount of pride that goes with that, and, you know, you feel like a scientist.

Like their students, faculty were aware that a key element in prompting both confidence and a sense of themselves as "real scientists" arose from professional colleagues taking a genuine interest in their work. Faculty also described these experiences as pivotal in helping students to feel part of the scientific community:

> Most of them, by the time that they've put their poster up on the last day. . . , I think they really do feel as if they've not only contributed something, but they're *part* of something. And I think they find that valuable.

For the smaller number of students who attended professional conferences (as opposed to conferences specifically for students), these effects were even greater. The following faculty comment illustrates the strong affective gains from such an experience:

> Oftentimes we'll take them to a national meeting, and then, then they'll *really* feel like they're part of the field. I mean, they're standing there in this big hall in front of a poster, and they really feel that they're, they've in a sense made it then, you know?

Faculty described the role that presenting their research plays in students' professional socialization:

> Watch them at their poster session, or watch them at a meeting, explaining what they've done to other chemists. . . . When you go to a [disciplinary] meeting, that's the key thing to do. And to watch all these chemists from Dow coming around to talk to students. . . . It's this big epiphany when they realize that what they're doing really is important and that somebody somewhere else actually cares about it, and they get into *real* scientific conversations, "Oh, well did you try this?" "No, but I tried that!" When something like that happens, and the student gets truly excited about it, that's the moment there.

Faculty were aware that students' confidence and satisfaction in what they were able to accomplish were not only gains as young scientists but also gains in self-discovery and personal growth. Faculty also recognized that these gains transferred to other areas of students' lives:

> I can't put my finger on it precisely, but certainly from the way they talk about it and the good feelings they seem to have later on about it, it seems to have been an experience in which they've had a tremendous sense of accomplishment. It's sort of bolstered their sense of themselves as, "This is something that I can do pretty much single-handedly. Look at this big body of work that I did in this 10-week period!" And they seem to be able to take from that a sense that they can achieve, that they can sort of organize their lives and organize their future activities. It seems to carry over, at least in their minds, in some sort of generalized sense. . . .

Faculty put considerable effort into arranging student presentation opportunities because they recognized the potential of these experiences to move promising young scientists toward a stronger identification with the profession of science and, possibly, commitment to becoming scientists.

The opportunity to build a close, collegial relationship with faculty was a benefit of UR discussed by both faculty and students. Descriptions of the importance to students of establishing collegial relationships were 24% of faculty observations, and 16% of students' observations, within the "personal-professional gains" category. Faculty advisors' observations showed that they are very conscious of their mentoring role and more aware than their students of the specific benefits of developing collegial relationships. Students largely focus on the powerful shift from a hierarchical and respectfully distanced relationship to one based on partnership:

> When I go in and explain what I found to him and he responds with my first response to the question, and I can say, "Now, I thought of it a little bit more, and I don't think that's exactly it," it's really wonderful to be in such a give-and-take with a professor, where the professor doesn't know all of my ideas before I come to it. . . . It's really neat to be with a professor and be working through something that is new for both of us.

Faculty likewise described the character of their interactions with their undergraduate researchers as one in which students became collaborators:

> Part of what I think works in this enterprise, is it's not this student–teacher relationship. It's a more collegial relationship. We're on fairly equal footing here. It's true I have a lot more experience, and I can give them the benefit of my general experience in thinking about mathematical problems, but I don't have any more specific insight into this problem. And it's wonderful when a student comes up with something and I say, "Well, that's really neat! I never thought of that." And they just beam, you know, "I got something!"

Faculty were also highly aware of the processes whereby genuine collaborations arise. They underscored the intensive nature of the UR experience: working with students on a daily basis for a sustained period created personal relationships that supported students during and beyond college:

> They've had some very intensive, extensive, one-on-one mentoring with a professional scientist. We work very closely with the students. . . . We watch them mature. We watch them struggle with decision-making during their college years. We participate in their

decision-making (laughing) during their college years. . . . We call them up short when they need somebody to. . . . We listen to their problems. It's just a very close relationship.

Faculty reiterated their longer term commitment to student researchers:

I think they see me sort of, at least for some period of their life, as sort of a mentor. As a person they can go to, to ask for recommendations, ask questions, get feedback, get my advice. I think that's very nice. I think, certainly, when you interact with somebody on a daily basis you usually get to know them much better.

They took a deliberate, active role in the processes that bonded students to science, to science learning, and to the community of scientists:

We feel it is the best way for students to learn about science. That is, if they really *do* science, they are going to also *learn* science. And it's just more active. It's more interesting. It's more exciting. It creates a bond between students and faculty, which is a very positive thing to try to create.

Students' observations on building collegial relationships with faculty provide insights into the mentoring role of faculty advisors. Faculty modeled how science is done, and, in doing so, gave their young colleagues the confidence that they too could handle the complexities of research. It is clear to students that their faculty advisors' appreciation and respect was genuine:

They're just a great resource. They're an expert in what you're doing, for one thing. So they have great ideas. And when you really hit that wall and you don't know what to do, and you've tried things, then you can go back to them and they will have some suggestions, or at least places to look for new things to do. I think that's really important. . . , the encouragement that you get from them. And like, how happy they are with your progress. I think that that can reflect to you, "Hey, you know, I can do this! Look, she thinks I did a good job!" . . . I think when *you* start asking questions and when *you* are able to say, "What do you think about trying it this way?" and they go, "Oh, I hadn't thought about that," that's really nice.

The greater number of faculty over student observations about the significance of establishing collegial faculty–student relationships likely represents faculty advisors' longer-term perspective and their greater awareness of the processes that draw young scholars into the scientific community. Faculty reflected upon the long-lasting associations and ongoing friendships that they developed with their former research students[6]:

There's a lawyer in Cedar Rapids that I've kept in touch with over the years. He was '76 class, something like that. And about every other year we get together someplace. We have a lot of mutual friends and we know what each other's doing. There's another guy, a faculty member, a mathematician. . . we see him all the time. He used to baby-sit for us. Their daughter was up a couple of weeks ago.

---

[6] The higher number of faculty observations also likely reflects the value faculty place on mentoring undergraduate researchers. As many of the above quotations demonstrate, faculty emphasized the intrinsic gains they receive from mentoring. Indeed, in a separate analysis (to be published) of the data of the costs and benefits to faculty for participation in UR, benefits cited by faculty are almost exclusively intrinsic, focusing on the rewards of fostering students' personal and professional growth.

I made a presentation about career development. You know, "How I got where I am.". . . . And when I was there, I looked out into the audience and virtually all of the students I had trained. . . were there, and they were cheering. And, afterwards, they came up and they were giving me hugs. And after all the students had left and we went to dinner with the other speakers, someone from Harvard said, "Well, I don't think my students would ever do that to me." And, you know, it was kind of a feeling that you had been a part of their lives and not just their scientific mentor. That was really satisfying.

Small numbers of both faculty and students' observations (13% and 9%, respectively) reported the value of gaining a collegial working relationship with their peers. Students described how working alongside other students provided mutual support when things did not go smoothly, extra insight into problems, and knowledgeable sources of ideas when the research advisor was unavailable:

We would also have meetings for lunch once a week where everybody from the two labs would get together and we'd discuss what we're working on so I wouldn't be totally out of the loop. . . . Even though I'm not specifically working on that project, what their work is influences my project and vice versa. So we would. . . discuss what had been going on—new results, something good or bad that had happened. . . . Plus, that provides time for insight. . . maybe they're thinking about this problem a different way than you.

Faculty particularly noted the educational benefits of having students work together and the value of the camaraderie and confidence this can generate:

I think. . . they learn a lot just from being around other students that do research. . . . They talk a lot. . . . The community aspect of it is very important in terms of support, like, "The other student has the same problem, so I'm probably doing okay. . . . I can do this!"

One fifth of faculty observations in the "personal-professional gains" category were not directly comparable to comments offered by students. These observations reflect faculty awareness of the multiple dimensions of student growth and processes generating these changes. Conscious of their role as mentors, some faculty actively worked to replace students' stereotypical ideas of scientists with more realistic views of who and what scientists are:

I think they get to see what a real scientist looks like. There aren't too many scientists that sit in their white coats and think, "$E = mc^2$" all day. So I think students get a picture of what a real scientist looks like. . . . I think my job description as a mentor is to be a scientist and to be a *person* who is a scientist. I mean, I'm sorta their little example of what a scientist is. And I hope it's a little different from what they maybe came in with.

Other gains of this type that faculty (but not their students) observed noted students' personal and professional growth in maturity and self-discovery, and benefits arising from belonging to a community of learners. Students' mentoring less-experienced researchers or being mentored by others (e.g., post docs, other scientists) was also mentioned as a gain.

Overall, in this category, faculty and students emphasized UR as an opportunity to discover the confidence to work independently and creatively as researchers; develop a sense of professional identity; and feel that they belong as colleagues to a community working together in common endeavor. Students also defined developing collegial relationships with faculty and with research peers as a type of personal-professional gain whose significance was strongly acknowledged by faculty. Faculty saw the longer term importance of

collegial relationships that grew out of UR experiences, describing long associations with former undergraduate researchers. Establishing collegial relationships with student peers working on the same projects also provided support when extra perspectives on research processes and problems were needed and when faculty advisors were unavailable. Thus, the gains comprising this category speak to students' growing internal sense of self as young scientists and reflect the significance of building professional relationships with faculty and peers that reinforce a shift in their identity and sense of belonging that they express as "feeling like a scientist."

Clarification, Confirmation, and Refinement of Career/Graduate School Intentions

This category is composed of observations on the role of UR in increasing students' interest in science and science research and in helping them to clarify, confirm, and refine future career plans, including graduate school. By number of observations offered, this category ranked fourth for faculty and fifth for students (Table 1).

A much higher percentage of observations were offered by faculty (57%) than by students (12%) on students' increased interest and enthusiasm for research or the field of study. This likely reflects faculty advisors' history of seeing many students extend their summer UR experience into the academic year and/or for several more summers.[7] Increased interest in science is an important outcome in itself, but faculty also see it as the first step toward a science career: from long experience, they see that students, once engaged, are apt to discover a larger sense of participating in science and become further involved:

> I've had students that worked with me during the summer, and then they've stayed the next year. Once they've started in the summer they enjoy the research and they stay during the academic year.

> Many of them gain a real excitement for the entire experience. In other words, starting off knowing almost nothing about the field, spending some time learning about the field, and then actually being *part* of the field.

Students also discussed their increased interest, but spoke only from the more immediate viewpoint of their recently completed summer research:

> I just gained a better love of the sciences and a better appreciation of them. And now that I've seen everything that's gone into [a research project], I have seen a little part of what goes into everything I've ever learned.

The UR experience was highly valued by both students and faculty because it provided an opportunity to affectively and cognitively assess how well research work matched with students' aptitudes, temperament, and life choices. Students appreciated the chance to gain an informed perspective on their career decisions and felt more confident in taking their next steps, especially the decision to go to graduate school. Faculty strongly concurred; as one faculty advisor put it, UR experience allowed students to "exercise wisdom before folly." On the basis of their long involvement, faculty see UR experience as helping students to clarify their interest in an area of study and settle the question of whether or not "research is for me." Thirty-six percent of students' observations and 20% of faculty observations in

---

[7] We are checking student accounts of multiple UR experiences in second- and third-round interviews.

this category described UR experience as instrumental in helping students find out "what will make them happy" and whether going to graduate school and pursuing a career in science research would be a good choice for them[8]:

> It's certainly nice to see them learn over the course of the summer, to see them doing more thinking for themselves, more autonomy, making good choices, making good decisions. It's nice to see them gain confidence in their role as research collaborators. It's nice to see them get to a point where they clarify what they do and don't want to do, because that really *does* often happen. . . . It's nice to see them clarify, "Yeah, that was interesting, but it's not my cup of tea," or, "Oh, I loved it and this is what I want to do!"

For students, the experience of "seeing myself doing this" is revealed as a critical element in the career clarification process:

> Just the experience of realizing, "Okay this is what my life is going to be like if I decide to do this," and realizing, "Yeah, that's what I want to do. That's what I enjoy doing. That's what I love doing."

> I've always wanted to be a professor, since I was a little kid. However, I never thought I'd really want to be a research professor, like I do now. . . . I can now see myself in someplace like Berkeley or someplace with a really big lab, where I've got 20 to 30 students working under me and kind of more running the shop. I can see myself doing that now, and I can see that because I have the experience in research and know how much I really love it.

As faculty also noted, the UR experience clarified for some students that research was not well suited to their interests and/or temperament. In this sample of 76 students, 7 found that "research is not for me":

> It's a lot of tedium. Setting up the laser, aligning it, spending two days tracking down a pump leak, changing the pump oil. I don't know if I have that much patience or desire to do that.

> I really do enjoy doing research, but I can't see myself doing it for my entire life. I can't see myself in a lab, day in and day out.

Again, we note the significance (in this case for career decisions) of the tests of temperament posed by the character of real research work:

> I would actually say the majority of students that I've had over the years in the summer research program came in convinced that they wanted to get a Ph.D. (laughs) and *that* changed their minds. I actually have had quite a few say that they're happy they had this experience because they never really realized what it was about, and that you have to be able to deal with frustrations and you have be patient and progress is very slow and all these things. You don't really understand that when you take a course at school.

---

[8] In our separate analysis of faculty advisors' comments on their objectives for UR, we found that the second highest number of "objectives" observations (20%) concerned the role of UR in helping students to clarify their career goals and to make appropriate career and/or graduate school decisions. Providing students a hands-on learning experience of science research ranked first (at 38%) among faculty members' objectives.

> . . . A student that worked for us for one semester, and at the end said, "No! I can't do this! You can't give me a set of instructions!" She's still in physics, so it wasn't to the point that we totally destroyed her dreams, but she quickly realized and said, "I can't! I can't deal with this uncertainty and ambiguity and not knowing at the beginning if it's even going to work out at the end."

The much larger number of observations offered by students (39%) than faculty (9%) on gains in clarifying and confirming interest in graduate school per se, rather than a specific interest in a science research career, probably reflects students' immediate and dominant preoccupation with what they will do beyond graduation. Most of their observations either expressed an increased interest in attending graduate school or confirmed a preexisting interest in graduate school. Students' observations also show that UR experience provided greater confidence in decision making about the future:

> I've always been thinking and wanting to go to grad school, ever since I can remember, wanting to get a doctorate, but I actually truly decided, it was this summer when I said, "Yes, I'm going to go to grad school. It's what I want to do."

> Up until this year I had always been dead set on grad school, no question. . . . I guess about part way through the year I was sort of wondering whether I really wanted to continue on in grad school. . . . But I really do think, after getting back into research, that I really want to go on in grad school.

In summary, for this sample of students at liberal arts colleges, we did *not* find that UR experience had prompted their decisions to go to graduate school. Rather, most students had planned for and anticipated a graduate school education. Thus, for this student group, we found that the role of UR was to increase students' interest in and probability of going on to graduate school, to confirm whether previous intentions to undertake graduate study were apposite, and to clarify or refine which field of interest to pursue. Faculty also saw increased interest as the first necessary step toward choice of a research-based science career. The UR experience was highly valued by both students and faculty because it provided an opportunity to affectively and cognitively assess how well research work fit with conceptions of their own aptitudes, temperament, and future life choices. Students appreciated the chance to gain an informed perspective on their career decisions and felt more confident in taking their next steps.

Enhanced Career/Graduate School Preparation

Career and graduate school enhancement benefits ranked fifth in number of faculty and sixth in number of students' comments (Table 1). That this set of observations has a relatively low ranking in the list of reported gains indicates that neither faculty nor students valued UR for predominantly instrumental reasons. Rather, both groups saw the pragmatic benefits of research experiences in preparing students for work or graduate education as ancillary rather than primary gains.

Half of the benefits in this category mentioned by faculty described formal contributions to science by undergraduate researchers. They included students who had presented at conferences, were listed as coauthors on articles, or who had made other contributions through their UR projects. The larger percentage of faculty members' estimates of career preparation gains clearly reflect the numbers of students they have brought to conferences and with whom they have published over the years. From their longer term perspective

as professional scientists and educators, they view co-presentation and shared publications with students as making valuable contributions to their own careers as well as having professional value for their students. Just 20% of students' observations mentioned this same type of gain.

In contrast, one third of student comments in this category described how UR provided "real-world work experience." For many students, summer research was their first experience of working full time, wholly engaged on a single project. Students saw this as of transferable value when they imagined what it would be like to work professionally:

> You're given a lot of freedom and responsibility to do things, so I'm really getting out of it how to go about a professional type job or business, these kinds of things.

For those students who were considering graduate school, UR was seen as a preliminary glimpse of what graduate work would demand of them:

> I think the whole experience is great preparation because it's far more similar to what graduate school is actually like, I've been told.

Twelve percent of faculty observations referenced UR as providing good preparation for graduate school (and other work contexts):

> I know our graduates typically make the transition to graduate school very easily, because we are really taking them from a typical undergraduate experience into a typical graduate experience by their senior year. . . . So I know they enter graduate school—of course they're terrified—but they quickly realize that they're better prepared than most people there. I'm thinking of two women in particular. . . who basically said that their peers in the graduate school class spent the first year learning to read and write scientifically. And they *knew* all that.

Sixteen percent of students' observations also recognized that UR experience would give a solid boost to their résumé and graduate school applications:

> I'm interested in going to graduate school and I think it'll help my chances a lot in getting into graduate school, to have done research as an undergraduate.

However, as we reported in our first article, in a separate analysis of students' motivations for undertaking UR, we found that the large majority (71%) of students' statements cited intrinsic interest or a desire to learn what research work entails. None of the students described their research experiences largely as a means to improve their career prospects, and no student described its benefits solely this way.

Faculty, too, were aware that listing research experience on a résumé or graduate school application would be of practical benefit to students. A small number of faculty observations in this category (8%) discussed the competitiveness of graduate schools and the added status graduate schools assigned to students citing UR on their applications:

> If you are interested in pursuing an advanced degree and you want to do it, of course, at a good institution, having research experience under your belt will be very, very helpful. Our students go to the best places, and I think, in large part, it's because, not only do they have As in the same math classes that students in other places do, but many of them have actual research experience. These graduate schools say, "This is not someone we have to gamble on. This person has something submitted or accepted for publication."

Nearly 30% of students' observations in this category also described UR as providing valuable professional connections. In their portrayal, this had both instrumental and purely intrinsic dimensions. In looking to the future, students valued meeting other scientists; they also appreciated the new possibilities that might be opened to them:

> I don't know if this will play out or not, or really how it works, but I have the added bonus of being connected with two or three other people in Seattle through this project. . . . So it sort of broadens my contacts. . . . And I hadn't thought of that at all when I started, but that may be something that later on turns out to be useful, something may turn up there.

A few faculty members reported that UR offered their students opportunities to network with other scientists (4%). Being able to meet and talk with other scientists helped students to envision what it would be like to be a working scientist. Faculty comments show understanding of the tacit role such experiences play in teaching students about work as professional scientists:

> The last two summers I've taken students with me to Duke University and students like the idea that they might travel someplace. . . . There's multiple other things going on there. Being that this is an undergraduate institution, students don't naturally interact with graduate students here. I take them to Duke, they get to meet some grad students who hang out with them. And they get an idea of what they're getting themselves into.

Twenty-six percent of faculty observations in this category addressed gains that students did not discuss. These observations reflect the multiple dimensions of the faculty mentor's role in UR. These included students receiving career advice and information from their advisors; letters of recommendation and help in procuring placement in other UR or internship positions and scholarship awards on the basis of the high quality of their UR work.

It is interesting that a majority of faculty's observations in the career preparation category reference either what might be called the "value-added" by UR or their own formal role as research advisors—both of which are important to departments and tenure review committees. Indeed, several faculty members informed us that they kept a running tally of the numbers of students they mentored in UR, as well as a current list of articles published with students. Because such numbers are overt indicators of students' "success" in UR as defined by their departments or institutions, and because they can be easily documented (or may be the *only* UR outcomes documented), they are commonly used in the merit system as measures of faculty achievement. Emphasis on these extrinsic gains to students seems to oblige faculty to take a somewhat instrumental attitude toward measures of UR benefits. This contrasts strongly with our evidence that faculty advisors focus more on the educational and professional benefits of their UR work for their students and on the intrinsic nature of its rewards for themselves as educators. The contrast between institutional pressures and faculty advisors' personal motivation for their UR work may also explain why extrinsic gains are so widely cited in the literature on UR, although (at least by our findings) they seem more often claimed or desired than achieved.[9]

[9] Numbers of students attending formal disciplinary meetings are relatively low compared to the number of students involved in UR. In this sample of 76 students, 21 reported attending off-campus symposia or conferences; this includes 7 who reported attending and or presenting at a professional meeting. Numbers of student publications are also low compared to the overall number of UR participants in UR. In this sample, five students reported co-authoring a published article. Reasons for these low numbers are very complex, not the least of which are issues of student readiness.

All students' observations in this category reflect their preoccupation with imminent decisions about life and work beyond college. As we have shown, students' motivations for undertaking UR (at least in this sample of liberal arts colleges) were primarily focused on intrinsic interest in the experience rather than on résumé enhancement or career preparation per se. However, it is apparent that, in the course of their UR experience, students were enabled to more clearly understand what work as a scientist entailed and appreciated the ways in which it had helped them to feel better prepared to meet its challenges. Faculty clearly noticed gains in students' readiness to undertake graduate work or careers in science and were aware that prospective graduate schools and future employers would look upon students' UR experience positively. Some faculty also noted the additional opportunities for some students to travel to conferences, other institutions, and laboratories. They saw these experiences as offering students further insight into what graduate school or a career in science entailed.

Gains in Skills

The category of gains focused on increases in students' skills ranked sixth in number of faculty observations and third for students' observations (Table 1). The higher percentage of student observations likely reflects the steep learning curve they encounter at the beginning of UR projects when learning new laboratory techniques and instrumentation and, later, the challenge of learning to present and defend their research in a professional manner. Faculty members also note students' gains in various skills, but, with the exception of presentation and communication skills, technical skills are reported less often and seem of less importance to them than to their students. Nearly half the gains in particular skills discussed by faculty and students concerned communication skills (45% and 43%, respectively). Thirty-two percent of faculty observations in this category and 22% of students' comments also discuss gains in laboratory skills and techniques necessary for research work. Gains in work organization and time management skills, computer skills, the ability to effectively read science literature, to work collaboratively, and to find and retrieve information were also mentioned by both groups, but to lesser degrees.

Faculty and students reported nearly equal gains in learning to present and defend an oral argument (37% and 36%), whereas improvement in scientific and professional writing skills were cited at much lower levels (8% and 7%). All of the UR programs in this sample emphasized teaching students how to present scientific results. Indeed, teaching students presentation skills was one of the more overt, formal objectives of these programs. Most faculty members clearly endorsed this emphasis. They discussed taking the time and effort to help students learn presentation skills and provided multiple opportunities for them to practice. They reported that most students did reasonably well in learning to defend their research but offered the caveat that few get to a high level of competence. They expected this skill to be developed further in graduate school. They agreed that teaching students to explain, discuss, and critique their work is a significant aspect of learning professional practice. However, little or no formal writing was required for most end-of-summer presentations; most commonly, students provided a summary of the work that had been accomplished, along with their laboratory notebooks. Few students were involved in assisting their research advisors in writing scholarly articles. Indeed, faculty discussed publishing coauthored papers as a benefit that "comes later" or beyond graduation.[10] Since research often takes years, and faculty members often have difficulty finding the time to write

---

[10] Kremmer and Bringle (1990) also found that, for a high proportion of their sample, publication of a coauthored article occurred months beyond the UR experience.

up their research results for publication, students may be well beyond graduation before faculty members are ready to publish. In addition, helping students to learn professional writing skills requires more time and effort than is possible during the available 10 weeks. Development of writing skills was mentioned as a gain largely for students doing a senior thesis (i.e., a student with sustained engagement and a writing task).

Gains in laboratory techniques and learning instrumentation were noted among the highest skill gains by both faculty and students (32% and 22%). As the research work required use of various techniques and instrumentation, students were obliged to quickly learn how to do new things. Faculty described the intensity of the early weeks of summer research in getting students "up and running." Learning one's way around the laboratory or being familiar enough with equipment to "figure it out" were sources of students' increased self-confidence to do science. For faculty, students' quick grasp of the work was essential if the time available was to be productive. Gains in computer skills are reported in lower numbers by faculty and students: both groups commonly described having to learn software programs used for modeling, analysis, or presentation, or programming languages. Smaller numbers of observations offered by faculty and students described increases in students' ability to manage their time effectively, comprehend and critique literature, and work collaboratively. A few students added as a gain learning how to do library, Internet, and database searches to find information.

Overall, the larger number of student over faculty observations on gains in skills suggests their importance to students. Students are challenged to learn a lot in a short time and, in the end, are proud of their accomplishments. Students discussed skill gains as enhancing their preparation for future work. They also reported gains in confidence in feeling comfortable in the laboratory that increased their willingness to work independently. Gains in confidence arising from presenting and discussing their work also helped students to feel part of the scientific endeavor. They described their skill gains as transferable and predicted that they would prove useful in graduate school, future work contexts, and other areas of life. Thus, skill gains had an iterative effect in enabling other types of gains and held utility for students beyond the immediate purposes of the research work. Although this category of gains is composed of the practical skills gained from UR, their import also carries affective benefits for students.

DISCUSSION

Faculty and students' observations on gains from UR experience provide particularly rich source material for examining the theoretical constructs proposed by social constructivist learning models of student learning and development discussed earlier in this article.

By faculty and student accounts, summer UR experiences at these colleges manifest social constructivist principles in praxis: it is an apprenticeship in which the novice learns over a period of time through hands-on experience how science research is done. The apprentice researcher learns cognitive and practical skills within the context of professional practice: authentic science research. The student's "situated" learning is supported by the research advisor, who, acting as a mentor, provides instruction, guidance, and direct modeling of how science is done professionally. Faculty and students work collaboratively in a partnership of mutual interest, where students' reflexive sharing of their thoughts on the progress and trials of "their project" is simultaneously supported by the expert guidance of the faculty research advisor. Projects are matched to meet students at their "level" and aimed at capturing a "zone of proximal development" that will stretch their capacities. Intensely engaged in applying knowledge and skills to this site of professional practice—a community of

practice—student researchers gain greater cognitive and practical skills, and continuously integrate their learning into daily work. With increasing experience and growth in their cognitive, personal, and professional capacities, students move away from the periphery to the center of practice as community members. This model of student learning affirms social constructivist theorists' views that learning is best achieved in a "situated" context that challenges students to apply and extend their cognitive and practical skills in a "zone of proximal development" (Brown et al., 1989; Farmer et al., 1992; Lave & Wenger, 1991; Vygotsky, 1978; Wenger, 1998). Faculty research advisors' role as facilitators of student learning and as collaborators working together with students in a mutual enterprise provides novice researchers with a cognitive apprenticeship. Students' legitimate peripheral participation in a community of practice encourages the development of students' thinking and practical skills necessary for professional practice through opportunities for two-way sharing between the apprentice and the master that encourage students' reflexive understanding of professional practice (Bockarie, 2002; Brown et al., 1989; Farmer et al., 1992). In this study, students and faculty clearly described a range of intellectual, personal, and professional transitions that they identify as outcomes of summer UR experiences and that also exemplify the social constructivist model of situated learning. In this comparative analysis, we have the benefit of both the "old-timer's" and the "newcomer's" points of view.

Observations comprising the "thinking and working like a scientist" category address the intellectual gains that are made in the situated context of an apprenticeship experience of authentic science research. Both faculty and students' observations affirm UR as an intellectual-experiential process: it provides students a hands-on learning experience of what it is to do science. Many faculty and student observations reported gains in applying their knowledge and skills to research work, although fewer mentioned increases in higher order thinking skills, particularly the development of a complex epistemological understanding of science or the ability to define a research question and develop experimental design. Findings from two studies investigating students' higher order intellectual skills (Kardash, 2000; Rauckhorst, 2001) and this study suggest that these types of gains are more difficult to achieve than gains in critical thinking and problem-solving skills that are substantiated by both faculty and students' accounts. Baxter Magolda's research supports the contention that researchers can expect to find evidence of the epistemological shift from "absolute knowing" to "transitional knowing" in some undergraduate samples, but that, for most young adults, shifts from "transitional" to "independent knowing" or to "contextual knowing" occur largely in the years beyond college. However, she advocates constructivist-developmental pedagogies (such as UR) that provide learning contexts that encourage epistemological development in students during college. She states: "Higher education focused on knowledge acquisition has trained students to be transitional knowers: alternative higher education contexts (e.g., focused on knowledge construction) might make complex meaning-making possible at much earlier ages. . . " (Baxter Magolda, 2004, p. 39).

Gains in developing a more complex epistemological understanding are valued by theorists and educators because the development of a more intricate view of knowledge is linked to understanding ambiguity and uncertainty as a condition of life. Preparing students for an "unknown future" is a longstanding tenet of education that is still viewed as a central purpose of colleges and universities today (Baxter Magolda, 1999, 2001, 2004; Bowden & Marton, 1998, 2004; Boyer Report, 1998; Dewey, 1933, 1938; Farmer et al., 1992; Freire, 1990; Giroux, 1988; Shor, 1987). As extracts from our text data show, faculty and students described the value of critical thinking and problem-solving skills developed from negotiating the inherent difficulties of research work as a decidedly applicable "life" skill.

Overall, both faculty and student observations affirm UR as an intellectual-experiential process of what it is to do science. In the context of doing science research, we note a process by which gains in intellectual skills from UR experience give rise to students' personal and professional growth. As evidenced by the interview data, opportunities for legitimate peripheral participation enabled students' cognitive growth and led to increases in their confidence to do research and contribute meaningfully to science. Faculty supported students' intellectual development by sharing their own thought processes and opinions, and encouraged students to do the same as they worked together collaboratively. The construction of shared meanings by reflective interaction between master and apprentice is a central feature of cognitive apprenticeships (Brown et al., 1989; Farmer et al., 1992). Interactive meaning-making between the master and the apprentice is also seen as critical in validating students as knowers and affirming their ability to meaningfully construct knowledge (Baxter Magolda, 1999; Freire, 1990; Giroux, 1988; Shor, 1987).

Wenger (1998) connects cognitive growth both to students' personal development and to assimilation into the community of practice: "membership within the community of practice translates in an identity as a form of competence" (p. 153). Thus, achievement of competence to work effectively influences students' personal identity development. Similarly, Baxter Magolda's model for self-authorship depends on the degree to which students shift from an external authority that validates their own knowing to reliance upon their own inner ways of knowing. In the same manner described by Wenger, development of cognitive abilities in the context of the community of practice builds confidence that is a mark of students' personal development. It also holds potential for furthering identity development as a young professional.

Like Baxter Magolda's research, literature on identity and career development emphasizes the social processes of knowledge construction and identity development (Billett & Somerville, 2004; Bockarie, 2002; Carlson, May, Loertscher, & Cobia, 2003; Cohen-Scali, 2003; Reybold, 2003). Again, the link between professional socialization and participation in a community of practice is emphasized: "socialization for work concerns attitudes, values and cognitive capacities acquired before entering the working world. Socialization by work, on the other hand, reflects the personal qualities that develop in young adults confronted with the working world" (Cohen-Scali, 2003, p. 239). Bockarie (2002) states:

> In a community of practice, social relations are created around work, and knowledge and its production becomes part of the individual identity and takes its place in the community. As opposed to being created to carry out a task, the shape and membership of a community of practice emerges in the process of activity as people work and learn collaboratively. The structures of the communities implicitly and explicitly lay out the terms and conditions for the members' legitimate participation, and define and set boundaries around learning. Communities of practice provide an essential context for the social production of knowledge, as well as the interpretative frames necessary for engaging in problem solving and problem finding to make sense of the world. (p. 51)

Thus, identity development and professional socialization are framed as a process of negotiated meaning-making within a community of practice. These same constructs apply to findings in our "becoming a scientist" and "personal-professional gains" categories as well, showing the interconnectedness of intellectual, personal, and professional development.

Observations collected in the "becoming a scientist" category support social constructivist theories relating to the development of a professional identity, where students' development of professional norms indicates greater integration into the community of practice and socialization into the profession. Students acknowledged changes in themselves as

outcomes of their UR experience. They reported shifts in attitudes toward learning and working as a researcher, such as taking greater responsibility for their work, increased willingness to propose next steps, acquiring tolerance for the frustrations and reversals inherent in authentic research, and greater intrinsic interest in science. Although students recognized these attitudinal and behavioral changes in themselves, they did not project them beyond the immediate context of their research work. Faculty members, however, regarded such gains as part of what it takes to "become a scientist." They see such gains as evidence of students' development as young professionals and as essential steps in their professional socialization into the practice of science and, therefore, as critical outcomes if the next generation of scientists is to be ensured.

In this category, faculty members' observations particularly reflect their position as witnesses to students' development. Observations of student gains in "becoming a scientist" describe the apprentice's move from the periphery inwards, assimilating behaviors and attitudes important to the community of practice. Faculty advisors' roles as educators and professional researchers influence their view of what they see students gain from UR. Faculty observe students' progress, assess how engaged they are in the research process, and look for signs that students are starting to act in a professional manner. Thus, faculty note when students begin to work independently, take "ownership" of the research project, become more willing to think creatively, or make decisions about next steps in the research. Faculty members, with their deeper experience of the profession, rightly interpret these new professional attitudes and mature behaviors as signs that their undergraduates are becoming good scientists. That students do not recognize these gains as professional attributes is the result of their relative viewpoint: they are, as yet, on the outside looking in. At this stage in their lives, students simply do not know what characteristics might be needed to become good scientists, and they are not conscious of developing such traits in themselves. However, as scientists, faculty members *do* know and it is apparent from their comments that they notice if and when students begin to take on particular attitudes and attributes that they deem necessary for professional practice. Gains in this category show students' personal and professional development and, thus, their greater identification with and integration into the community of practice.

The "personal-professional gains" category was the largest set of gains identified and directly linked by students to aspects of their hands-on research engagement. Students' observations discussed gains in their confidence to do research and contribute to science, the significance of building professional relationships with faculty and peers, and the shift in their identity and sense of belonging that they express as "feeling like a scientist." As social constructivist theorists indicate, the role of the faculty research advisor as a colleague who facilitates learning through expert guidance and who provides opportunities for students to share their interpretations and ways of understanding, appear to be critical elements in supporting students' personal growth and sense of self as a young professional. Indeed, Dobrow and Higgins (2005) state that "one of the most important functions of mentoring is the cultivation of professional identity" (p. 567). As extracts from the interview data show, the novelty of interacting with faculty as colleagues was a major source of students' growing confidence. Similar to findings from Baxter Magolda's (1999) research, which emphasize the contribution of the reflective process in encouraging students to see themselves as competent, faculty and students' accounts describe how treating students as collaborators and respecting their insights and contributions to faculty advisors' research affirmed their position as capable learners and encouraged a sense of self that they, too, could do science.

Students' personal and professional gains in confidence in "feeling like a scientist" were related to two formative experiences: coming to a clear understanding of the nature of research work, and in presenting at or attending professional conferences. In both cases,

the development of initial identification with the profession arises from a greater awareness of one's own self and reliance upon an inner authority. Tests of temperament against the realities of research work required students to asses their own capacity and readiness to engage in this type of work; presenting at and attending conferences induced students to imagine what their life might look like as a future scientist, drawing on an inner reflection and projection of their self in relation to current notions.

Faculty appreciated that increases in students' confidence in their ability to meaningfully engage in and contribute to science were, in turn, critical formative elements in students' development as young researchers and in their initial identification as scientists. However, faculty members emphasized the longer term importance of collegial relationships that grew out of UR experiences; they described long associations with former undergraduate researchers, many of which lasted years beyond summer research. Faculty members' observations reflect their awareness of the value of their role as a mentor, whereas the most distinctive characteristic of students' reports of benefits from UR is their focus on personal-professional transitions.

Overwhelmingly, students define UR as a powerful affective, behavioral, and personal discovery experience whose dimensions have profound significance for their emergent adult identity, sense of career direction, and intellectual and professional development. Students' observations on gains related to their confidence to do science and to contribute meaningfully to research reflect the affirming nature of the working relationship they experience with their faculty research advisors and highlights the significance of the multiple roles faculty members play as research advisors. Benefits cited by faculty and students of peer collegiality within the research group itself, within the larger summer UR student community, and in opportunities to interact with graduate students or scientists associated with the research locally or long distance, address additional networks supporting students' professional socialization: research group peers provided camaraderie, assistance, and opportunities to work collaboratively; meeting graduate students at research universities gave them ideas of future possibilities; and e-mailing researchers at a distance and receiving answers helped students truly feel membership in the community of science. From our data, it seems evident that legitimate participation in a community of practice engenders a process of self-reflection as students construct personal meaning from the experience, including the development of a professional identity.

Observations collected in the "career clarification" category discussed faculty and students' observations on how UR experience had increased students' interest in and enthusiasm for science, validated their disciplinary interests and clarified, confirmed, and refined career intentions, including going on to graduate school. These gains described personal and professional identity development as outcomes of UR experience. The goal of an apprenticeship is to teach the knowledge and skills necessary for professional practice. For students, UR served as a trial run of what it would be like to work in science research. As is clear from the text data, UR experience was valued as an opportunity to cognitively and affectively assess how well work as a researcher fit with students' aptitudes, temperament, and life choices. Students' observations emphasized the chance to "try on" science research as a profession and talked about "being able to see myself doing this kind of work." Faculty members confirmed students' accounts and agreed that UR experience was important in helping students to determine the correctness of possible career choices, especially graduate school. They concurred that having the opportunity as an undergraduate to see both what work as a researcher is like and what a future in graduate school would entail was valuable. While faculty hoped that qualified students would continue in graduate school, they were even happier for students to decide what would be right for them. In our sample of 76 students, 7 discovered that "research is not for me." For these students, the experience of

hands-on research had shown them that they were not well suited to the work; for many, coming to a clear understanding of the nature of research work was enough to settle the issue.

Most faculty members' observations in the career clarification category discussed seeing an increase in students' interest and enthusiasm for their field of study, or in science, generally. In early constructivist models of learning, Wood, Bruner, and Ross (1976) presented six steps upon which student learning is "scaffolded": interest in the activity is listed first (cited in Green, 2005, p. 295). Billett (1996) also states that intrinsic interest is an important precursor to learning and "emerges from the desire to understand, to construct meaning" (cited in Kerka, 1997, p. 2). Undergraduate research experience confirmed many students' preexisting interest in attending graduate school: we did not find in this sample of very able and highly motivated students that UR had *introduced* the idea of going to graduate school; many had intended graduate study prior to college entry. The low number of student observations on career clarification (this category ranked fifth) reflects students' ongoing uncertainty: as rising seniors, and at a time in life when the world seems wide open, students were still unclear about what they might like to do professionally. We will have to wait until final analysis of the longitudinal data is done to comment on the career outcomes of this student population and whether and how cognitive, personal, and professional gains from UR experience encouraged students' career choices.

Again, literature on career development is relevant to these findings. Baxter Magolda (2004) notes that college students nearing graduation faced with having to make decisions about what they might do beyond school, "search for ways to make decisions in the face of increasing uncertainty." According to Baxter Magolda (2004), this "unknown future" encourages a shift in knowing from "transitional knowing" to 'independent knowing' (p. 37). Cohen-Scali's (2003) work on the development of professional identity quotes Dubar (1991) concerning professional identity formation: "Basic professional identity not only constitutes an identity at work but also and more importantly a projection of oneself in the future, the anticipation of a career path and the implementation of a work-based logic, or even better a training oriented logic" (p. 239). As with our text data, we see that one of the functions of apprenticeship learning is that it allows students the experiential opportunity to assess the appropriateness of a possible future career in science research.

Similar to gains in career clarification, students' observations on how UR experience "enhanced career preparation" reference summer research as a "real-world" work experience that helped them to see what professional work in science entailed. In this category, and in the skills category, we see an emphasis in students' observations on the transferable value of gains from UR experience. Faculty also saw the transferable value of hands-on experience and reported gains in students' preparation for future work, whatever its nature. Faculty and students' observations also show the value of opportunities to network with other scientists, faculty, and peers. Being able to meet and talk with other scientists helped students to envision what it would be like to be a working scientist. This set of observations addresses the important role of other community of practice members, aside from the master, who actively contribute to students' learning and professional socialization.

Fewer faculty and student observations also discussed the value of research experience for enhancing résumés and job applications, indicating a low level of instrumental attitudes for undertaking UR. What is striking, however, is the emphasis of faculty observations on the "value-added" products of UR, such as numbers of student coauthored papers and conference presentations. Although such achievements undoubtedly enhance students' preparation, we sense a strain between faculty research advisors' roles as scholars, mentors, and educators and the need to "prove" the value of their endeavors to their departments and institutions.

Faculty and students' observations on "skills" highlight gains in learning to present and in learning laboratory techniques and instrumentation. These skill gains had an iterative effect on other types of student gain. Students learned that good communication skills were necessary to professional practice. Technical skill and knowledge that students continually applied to research work developed cognitive skills, especially in attempts to move beyond the various "unknowns" inherent to science research. Competence in managing difficult techniques or unfamiliar instrumentation affirmed students' ability to legitimately partici-pate in professional practice and provided a basis of professional socialization that further integrated membership in the community of practice. Students and faculty underscored the transferable value of skill gains to future work settings and framed these as good life skills.

CONCLUSIONS AND FUTURE DIRECTIONS

The comparative analysis of data from the faculty advisor interviews and those from the first-round student researcher interviews produced strong concurrence on the extent and nature of UR benefits. First, there was a high level of agreement between students and faculty that the UR experience was highly beneficial: 90% of faculty and 92% of students' evaluative observations contained accounts of specific gains from UR participation.[11]

Second, faculty observations on students' gains from UR also correspond strongly with those described by students. No major types of gains were identified by faculty that we did not also find among students' reports. This finding encourages us to think that the range and type of student gains that we have identified in the context of liberal arts college summer UR programs are qualitatively valid.

We also found a high degree of congruence between faculty and student benefits state-ments, both in broad and in the detail offered. The categories that we labeled "thinking like a scientist," "becoming a scientist," and "personal-professional gains" are notably interde-pendent and reciprocal. Taken together, these three categories account for 62% of all gains observations offered by faculty and 61% of gains observations offered by students. Thus, almost two thirds of the gains statements reported by faculty and students describe growth in understanding both salient areas of science and how to apply knowledge to the professional practice of science; concomitant development of students' confidence and competence in doing research; personal growth in the attitudes, behaviors, and temperament required in a researcher; and the beginnings of identification with and bonding to science as an enterprise. Faculty accounts of students' gains emphasize even more clearly than did students' reports the critical role played by UR experiences in helping students to find themselves as young scientists. Both faculty and students' observations affirm UR as an intellectual-experiential process: it provides students a hands-on learning opportunity of what it is to do science, and to some degree, to develop higher order cognitive skills. In many ways, all student gains categories address aspects of the broader theme of "becoming a scientist."

Results from our comparative analysis of faculty and students' perceptions of gains from apprentice-style UR exemplify social constructivist theories and models of student learning and highlight the processes whereby these benefits are generated within a community of practice, including students' cognitive and personal growth, and the development of professional identity. Thus, these findings support objectives and recommendations by the 2002 Boyer Commission Report and funding agencies and organizations promoting

---

[11] The duplication of comments counted in both the "personal-professional gains" and the "becoming a scientist" categories as a result of revising student gains categories increases the percentage of students' observations on gains from UR to 92%. In Seymour et al. (2004), as cited at the beginning of this article, we originally reported this as 91%.

college science education (NSF, 2000, 2003a; National Research Council, 1999, 2000, 2003a, 2003b) that UR in this type of program is (as many faculty claim but few studies have documented) an ideal way to learn science. These UR programs provided a learning context that affords the opportunity for personal growth and self-understanding that Baxter Magolda (1999) describes as "self-authorship." As we concluded in our first article, to focus on institutional and extrinsic measures of success for UR, rather than on students' personal, intellectual, and professional growth, is to miss the point. The findings of our study thus far strongly underwrite the faith that faculty, institutions, and UR program funders have placed in the value of UR experiences for science students. However, our findings place more emphasis on intrinsic, educational, and professional benefits and less on extrinsic and institutional gains than may be found in some institutional claims for their UR programs.

We chose to conduct this study at four liberal arts colleges with a long history of well-developed UR programs because findings would represent the "best case." As mentioned at the beginning of this article, other recently published studies on UR show broad agreement on gains from UR that we have found, though other reports provide little or no discussion of some of the stronger gains that we document, such as students' personal and professional growth, and significant variation in how particular gains (especially intellectual gains) are defined. Literature on social constructivism and communities of practice offers caveats about how legitimate peripheral participation is defined in practice (Baxter Magolda, 2001; Bockarie, 2002; Hay, 1993). Because the types of activity students engage in are important to cognitive, personal, and professional development, it is crucial that students have legitimate participation. For instance, bottle washing may be a necessary part of laboratory research, but if a student is left to wash bottles every day, it is unlikely that he or she will make the same gains as a student who is actively engaged and making decisions about how best to move the research forward. Within the context of research universities—where the large majority of students undertake UR—we predict higher variability in the quality of these experiences and in the types of gains that students take away from the experience. Further research to better define UR experiences at research universities would facilitate a comprehensive understanding of gains to students from UR experiences in these institutions. Our hope is that a better research-grounded understanding of what constitutes the character and significance of student gains and the processes whereby these are generated in the array of academic contexts and types of UR experience available to students will allow the community of UR practitioners to move forward in meaningful practice and evaluation of their work.

REFERENCES

Adhikari, N., & Nolan, D. (2002). "But what good came of it at last?": How to assess the value of undergraduate research. Notices of the AMS, 49(10), 1252–1257.

Barlow, A., & Villarejo, M. (2004). Making a difference for minorities: Evaluation of an educational enrichment program. Journal of Research in Science Teaching, 41(9), 861–881.

Bauer, K. W., & Bennett, J. S. (2003). Alumni perceptions used to assess undergraduate research experience. The Journal of Higher Education, 74(2), 210–230.

Baxter Magolda, M. B. (1999). Creating contexts for learning and self-authorship: Constructive developmental pedagogy. Nashville, TN: Vanderbilt University Press.

Baxter Magolda, M. B. (2001). Making their own way: Narratives for transforming higher education to promote self-development. Sterling, VA: Stylus.

Baxter Magolda, M. B. (2004). Evolution of a constructivist conceptualization of epistemological reflection. Educational Psychologist, 39(1), 31–42.

Berger, P. L., & Luckman, T. (1967). The social construction of reality. London: Penguin Press.

Billett, S. (1996). Towards a model of workplace learning: The learning curriculum. Studies in Continuing Education, 18(1), 43–58.

Billett, S., & Somerville, M. (2004). Transformations at work: Identity and learning. Studies in Continuing Education, 26(2), 309–326.

Blumer, H. (1969). Symbolic interactionism: Perspectives and methods. Englewood Cliffs, NJ: Prentice-Hall.

Bockarie, A. (2002). The potential of Vygotsky's contributions to our understanding of cognitive apprenticeship as a process of development in adult vocational and technical education. Journal of Career and Technical Education, 19(1), 47–66.

Boyer Commission on Educating Undergraduates in the Research University (1998). Reinventing undergraduate education: A blueprint for America's research universities. S.S. Kenny (chair). State University of New York-Stony Brook.

Boyer Commission on Educating Undergraduates in the Research University. (2002). Reinventing undergraduate education: Three years after the Boyer Report. S.S. Kenny (chair). State University of New York-Stony Brook.

Bowden, J., & Marton, F. (1998). The university of learning: Beyond quality and competence in higher education. London: Kogan Page.

Bowden, J., & Marton, F. (2004). The university of learning: Beyond quality and competence in higher education (paperback ed.). London: RoutledgeFalmer.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. Educational Researcher, 18(1), 32–42.

Carlson, N. M., May, W. E., Loertscher, R., & Cobia, C. (2003, Spring). Apprenticeship: Applications in adult education. Journal of Adult Education, 32(1), 29–43.

Cohen-Scali, V. (2003). The influence of family, social and work socialization on construction of the professional development of young adults. Journal of Career Development, 29(4), 237–249.

Dewey, J. (1933). Experience and education. New York: Macmillan.

Dewey, J. (1938). How we think. Lexington, MA: Heath.

Dobrow, S. R., & Higgins, M. C. (2005). Developmental networks and professional identity: A longitudinal study. Career Development International, 10(6/7), 567–583.

Dubar, C. (1991). La socialisation, construction des identités sociales et professionnelle. Paris: Armand Colin Editeur.

Dunn, J. G., & Phillips, D. N. (1998). Introducing second-year chemistry students to research work through mini-projects. Journal of Chemical Education, 75(7), 866–869.

Farmer, J. A., Buckmaster, A., & LeGrand, B. (1992). Cognitive apprenticeship: Implications for continuing professional development. New Directions for Adult and Continuing Education, 55, 41–49.

Freire, P. (1990). Pedagogy of the oppressed. New York: Continuum.

Garfinkel, H. (1967). Studies in ethnomethodology. Englewood Cliffs, NJ: Prentice-Hall.

Giroux, H. (1988). Schooling and the struggle for public life: Critical pedagogy in the modern age. Minneapolis: University of Minnesota Press.

Green, P. (2005). Space of influence: A framework for analysis of an individual's contribution within communities of practice. Higher Education Research and Development, 24(4), 293–307.

Gueldner, S. H., Clayton, G. M., Bramlett, M. H., & Boettcher, J. H. (1993). The undergraduate student as research assistant. Nurse Educator, 18(3): 18–21.

Hathaway, R., Nagda, B., & Gregerman, S. (2002). The relationship of undergraduate research participation to graduate and professional educational pursuit: An empirical study. Journal of College Student Development, 43(5), 614–631.

Hay, K. (1993). Legitimate peripheral participation, instructionism and constructivism: Whose situation is it anyway? Educational Technology, 33(3), 33–38.

Hunter, A.-B., Laursen, S. L., & Seymour, E. (2006, February 10–11). Benefits of participating in undergraduate research in science: A comparative analysis of student and faculty perceptions. Paper presented at the Texas Tech University, Lubbock, TX.

Jungck, J. R., Harris, M., Mercuri, R., & Tusin, J. (2004, Spring). Undergraduates: Do research, publish! Cell Biology Education, 3, 24–27.

Kardash, C. M. (2000). Evaluation of an undergraduate research experience: Perceptions of undergraduate interns and their faculty mentors. Journal of Educational Psychology, 92(1), 191–201.

Kerka, S. (1997). Constructivism, workplace learning, and vocational education (ERIC Digest No. 181, Accession No. ED407573). Columbus, OH: ERIC Clearinghouse on Adult Career and Vocational Education.

Kremmer, J. F., & Bringle, R. G. (1990). The effects of an intensive research experience on the careers of talented undergraduates. Journal of Research and Development in Education, 24(1), 1–5.

Lave, J., & Wenger, E. (1991). Situated learning: Legitimate peripheral participation. Cambridge, MA: Cambridge University Press.

Lopatto, D. (2004a). Survey of Undergraduate Research Experiences (SURE): First findings. Cell Biology Education, 3, 270–277.

Lopatto, D. (2004b). What undergraduate research can tell us about research on learning. Retrieved March 30, 2005, from http://www.pkal.org/template2.cfm?c_id=1002

Mead, G. M. (1934). Mind, self and society. Chicago: University Press of Chicago.

Nagda, B. A., Gregerman, S. R., Jonides, J., von Hippel, W., & Lerner, J. S. (1998). Undergraduate student-faculty research partnerships affect student retention. The Review of Higher Education, 22(1), 55–72.

National Research Council, Committee on Undergraduate Science Education, Center for Science, Mathematics, and Engineering Education. (1999). Transforming undergraduate education in science, mathematics, engineering and technology. Washington, DC: National Academies Press.

National Research Council, Committee on Developments in the Science of Learning, Committee on Learning Research and Educational Practice, Commission on Behavioral and Social Sciences and Education. (2000). In J. D. Bransford, A. L. Brown, & R. R. Cocking (Eds.), How people learn: Brain, mind, experience and school, expanded edition. Washington, DC: National Academies Press.

National Research Council, Committee on Undergraduate Biology Education to Prepare Research Scientists for the 21st Century, Board on Life Sciences. (2003a). BIO2010: Transforming undergraduate education for future research biologists. Washington, DC: National Academies Press.

National Research Council, Committee on Recognizing, Evaluating, Rewarding and Developing Excellence in Teaching of Undergraduate Science, Mathematics, Engineering, and Technology, Center for Education, Division of Behavioral and Social Sciences and Education. (2003b). In M. A. Fox & N. Hackerman (Eds.), Evaluating and improving undergraduate teaching in science, technology, engineering and mathematics. Washington, DC: National Academies Press.

National Science Foundation. (2000). NSF GPRA Strategic Plan, FY 2002–2006 (NSF Publication 0104). Retrieved March 25, 2005, from http://www.nsf.gov/od/gpra

National Science Foundation. (2003a, March 30–April 1). Exploring the concept of undergraduate research centers: A report on the NSF workshop. Arlington, VA: Division of Chemistry, Office of Special Projects, Office of Multidisciplinary Activities, MPS Directorate.

National Science Foundation. (2003b, August 2–4). Enhancing research in the Chemical sciences at predominantly undergraduate institutions. Report from the Undergraduate Research Summit. Lewiston, ME: Bates College.

Nikolova Eddins, S. G., Williams, D. F., Buschek, D., Porter, D., & Kineke, G. (1997). Searching for a prominent role of research in undergraduate education: Project interface. Journal on Excellence in College Teaching, 8(1), 69–81.

Rauckhorst, W. H. (2001, July). Measuring the impact of the undergraduate research experience on student intellectual development. Paper presented at Project Kaleidoscope Summer Institute, Snowbird, UT.

Reybold, L. E. (2003). Pathways to the professorate: The development of faculty identity in education. Innovative Higher Education, (27)4, 235–252.

Russell, S. H. (2005, November). Evaluation of NSF support for undergraduate research opportunities: 2003 NSF-program participant survey (Draft Final Report to the NSF). Menlo Park, CA: SRI International. Retrieved February 19, 2006, from http://www.sri.com/policy/csted/reports/

Schutz, A., & Luckman, T. (1974). The structures of the life world. London: Heinemann.

Seidel, J. V. (1998). The Ethnograph: A program for the computer-assisted analysis of text-based data (Version 5.0). Qualis Research. Thousand Oaks, CA: Scolari Sage Publications Software.

Seymour, E., Hunter, A.-B., Laursen, S. L., & DeAntoni, T. (2004). Establishing the benefits of research experiences for undergraduates in the sciences: First findings from a three-year study. Science Education, 88(4), 493–534.

Shor, I. (1987). Critical teaching and everyday life. Chicago: University of Chicago Press.

Strauss, A. (1987). Qualitative analysis for social scientists. New York: Cambridge University Press.

Vygotsky, L. S. (1978). Mind in society: The development of higher psychological processes. Cambridge, MA: Harvard University Press.

Ward, C., Bennett, J., & Bauer, K. (2002). Content analysis of undergraduate research student evaluations. Retrieved March 2005 from http://www.udel.edu/RAIRE

Wenger, E. (1998). Communities of practice: Learning, meaning and identity. Cambridge, MA: Cambridge University Press.

Wenzel, T. (2003). Definitions of undergraduate research. Retrieved April 12, 2006, from http://abacus.bates.edu/acad/depts/chemistry/twenzel/definition.pdf

Wood, D., Bruner, J., & Ross, G. (1976). The role of tutoring in problem solving. Child Psychology and Psychiatry, 17(1), 89–100.

Zydney, A. L., Bennett, J. S., Shahid, A., & Bauer, K. W. (2002a). Impact of undergraduate research experience in engineering. Journal of Engineering Education, 91(2), 151–157.

Zydney, A., Bennett, J., Shahid, A., & Bauer, K. (2002b). Faculty perspectives regarding the undergraduate research experience in science and engineering. Journal of Engineering Education, 91(3), 291–297.