The Impact of Undergraduate Research Experiences on Student Intellectual Growth, Affective Development, and Interest in Doing Graduate Work in STEM:

A review of the empirical literature

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Introduction

This review was undertaken to answer the primary question, "Does participation in undergraduate research (UGR) in Science and Engineering (S&E) affect the likelihood that participants will enter S&E graduate programs and succeed?"

This question is one of a cluster of questions addressed in the published literature on the effects of undergraduate research. Typically such studies examine the impact of UGR on:

1. Probability of transitioning to graduate school after earning the bachelor's degree

2. Changes in the "depth of commitment" or "level of interest" to continue into graduate school (because many UGR participants were already planning to attend graduate school)

3. Decisions or plans to pursue a career in S&E, especially in research

4. Research skills learned by students
    a. Operating lab equipment
    b. Learning appropriate statistical analyses
    c. Learning to read and synthesize prior research papers
    d. Learning to find key prior research papers (use a library)
    e. Learning to work independently
    f. Learning to write in appropriate scientific styles

5. Learning to think like a scientist

6. Communication skills
    a. Presentation skills
    b. Work effectively with faculty and graduate students
    c. Work with peers on teams

Some studies also have considered the costs and benefits of UGR, and the limits of UGR. For example, at the limit of department size, what is the percentage of majors that can be effectively included in quality undergraduate research?

Weaknesses of empirical studies

The quality of extant research is limited by the nature of the data available to studies, the heavy reliance on student responses to questionnaires, and the difficulty of quantifying the impact of a relatively heterogeneous "treatment" (UGR). Fortunately, it appears that the majority of the actual UGR experiences studied were of fairly high quality themselves – effectively designed for their clients, the undergraduate students.

In addressing the main question of impact on decisions to do graduate work, a list of difficulties faced in the empirical studies would have to include at least the following items:

1. In many places (e.g. REU = "Research Experiences for Undergraduates" projects) students selected to participate in UGR are already high achieving and oriented towards graduate school.

2. There are very few studies of the impact of undergraduate research on *average or typical* STEM students. Broadening the evident range of student capability would be a more useful and powerful test of the impact of undergraduate research on student achievement and continuation into graduate programs.

3. Lack of control groups matched to the treatment groups forces most studies to use a pre- post-evaluation of undergraduate research experiences, relying on student and faculty mentor responses to survey questions.

4. Most studies are do not actually observe student choices for long enough time periods to determine objectively actual effects. What is the probability that student "plans" to actually attend graduate programs will actually be realized -- let alone careers intentions? We do know from years of looking at first-time freshmen responses on the *American Freshman: National Norms* surveys conducted by the Higher Education Research Institute at UCLA that freshman intentions for graduate school – particularly doctoral study – are considerably more optimistic than what actually happens years later. (This is may be why a number of studies survey the depth of student commitment to go to graduate school or plan an S&E career.)

5. In larger scale studies such as program evaluations, there is incomplete control on the nature undergraduate research experience itself, other than built in quality control procedures (such as peer review in the case of REU awards). However, while the experiences and the disciplines covered do vary, most experiences appear to be carefully constructed.

6. Virtually all of the data are survey based. Student and faculty respondents code their answers using 5-point (or 4-point) Likert scales. Item construction can be critical in this context – the difference between a "5" and a "4" can be influenced by how these numbers are represented verbally, and there is little hope that the studies in this review are fully comparable. [Due to time limitations I did not explore this further in this review.]

7. The mix of undergraduate disciplines seems to matter a great deal. In the absence of UGR opportunities, bachelor's graduates in engineering are much less likely to attend graduate school in the near future compared to bachelor's graduates in (say) physics.

8. The measurement construct itself (change in the percentage of UGR participants planning graduate study) is tricky to compare across studies where some include only the best students and others also include "average" students. "Interventions" such as UGR have been found in other studies to lower undergraduate student attrition. (The reduced attrition can be attributed to mix of cognitive and affective gains and, in many cases, financially competitive summer stipends. E.g. students in NSF or HHMI sponsored summer research get attractive stipends.) This creates a larger post-UGR survivor pool responding to the survey, but one that may have a lower proclivity to engage graduate work initially and a bigger potential for gains.

<u>Consistent observations in the published studies covered in this review</u>

1. Virtually all of these studies have examined, in some detail, increased learning and improved affect (deeper commitment) of UGR participants. They report compelling qualitative findings that indicate convincingly that most UGR participants derive strong growth and development benefits, and a much broader sense of career options.

2. These gains in knowledge about career options often have the paradoxical effect of increasing student uncertainly about career plans. However, this uncertainty is primarily the result of much richer knowledge.

3. The measured benefits are plausible, often impressive, and in some cases based on very careful and detailed interview data.

4. Their findings are broadly consistent (with occasional exceptions) across studies.

Summary of findings -- transition to graduate programs [Refer to Summary Table 1]

1. The effect of UGR on the transition rates of students who are in highly selective colleges and/or who are in highly competitive summer programs is very modest. In the studies reviewed below:
    a. Lopatto found 27% of the participants in predominantly HHMI-funded summer research had deeper commitments to attend graduate school, but only 4% more had decided definitely to enter graduate school, which was more than offset by 5% who decided this career track was not for them.
    b. The study by Hunter, Laursen, and Seymour of students doing UGR in four selective liberal arts colleges found no students who changed plans in favor of attending graduate school (despite impressive developmental gains) but an attrition of 9% by students who learned this career track was not for them.
    c. The study by Gonzalez-Espada of high achieving undergraduates doing research at the National Weather Center found a significant effect on the basis of a deeper commitment to attend graduate school (37%) compared to a reduced commitment or change of plans (11%). However, when the focus was on career plans; gains (32%) were offset by losses (29%).

2. When the domains of institutional selectivity, project or program selectivity, and student achievement were broader, the gains in transition rates to graduate school were higher. Four studies are covered in this summary review that have some of these elements.
    a. The Zydney study of engineering graduates from the University of Delaware during 1982-1997 examined the impact of UGR programs that were open to all students. In his sample, 64% of the engineering alumni had participated in formal (37%) or other forms (27%) of UGR. The fraction of the graduates who had participated in formal UGR programs that subsequently enrolled in graduate school was 30 percentage points higher (at 80%) than the group who chose not to participate in UGR (50%). The fraction of alumni who engaged in PhD-level studies was 27 percentage points higher (35% compared to 8%).

    b. However, in Zydney's study the average GPA of participants in formal UGR programs was also higher (3.52 vs. 3.33). A comparison with the 27% who participated in "other" forms of UGR with an average GPA of 3.37 might be better. 67% of these graduates were subsequently enrolled in graduate school -- 17 percentage points higher (and 20 percentage points higher in the case of PhD level studies). However, a confounding factor is that the average student rating of formal UGR was significantly higher than the average rating of "other" UGR. The Bauer study, discussed next, tried to adjust for all confounding effects.

c. The Zydney study also shows that other major activities as well as UGR were also judged by the graduates to be effective and valuable. Highest rated were internships related to the engineering major. (Hackett reported a similar finding in a 1992 study that examined *Coop* internships and UGR of students in a technical college; summarized below.) Studying abroad and doing a senior thesis were rated about as highly as formal UGR experiences.

d. This study also discovered that the impact of UGR was higher and on par with the very highly rated internships in engineering in cases where 4 or more semesters of UGR were done. However, this could be an example of self-selection bias too.

e. The Bauer study was similar to the Zydney study except that it covered all of the STEM fields at the University of Delaware, not just engineering, and attempted to adjust for total effects in estimating the effect of UGR alone. This adjustment included discipline effects. Bauer estimated that 67% of the typical STEM graduates (with a 3.5 GPA) who had formal UGR experiences subsequently did graduate work, compared to 57% of alumni with no UGR experiences. Similarly, the probability of STEM alumni with formal UGR experience pursuing a doctoral degree was 43%, compared to 36% for alumni with "other" UGR experience, and 23% for remaining alumni. These differences at the PhD level are among the largest discussed in this review.

f. The Russell evaluation study performed under NSF contract to SRI International had the largest survey population. It covered all of the NSF-supported UGR experiences supported in 2002 in REU, RUI (Research in Undergraduate Institutions), and a host of other programs, including targeted programs. (These are described in the summary of this study below.) The survey population included a large number of minorities and women. 15% of the respondents had GPAs below 3.0 and 28% were in the range 3.0 to 3.5. Thus, the evaluation looked at a significant fraction of average and moderately above average students.

g. Russell measured large gains in "raised expectations;" 43 percent of student participants increased their education plans to attend graduate school and only 6 percent reduced their education plans. There was a net gain of 16 percentage points in the fraction planning to do doctoral work and another "gain" of 6 percentage points at the expense of medical school plans. (Unfortunately, this study did not report gains and losses separately, but only reports net gains at the PhD level.)

h. More than a decade earlier, Fitzsimmons and his colleagues at Abt Associates reported smaller effects on student plans to do doctoral work in an evaluation of the early years of the NSF REU program. (Unfortunately, this study also did not report gains and losses separately, but only reports net gains.) The net gain in students planning to do doctoral work after their UGR experience was 12 percentage points. This study also found that 17% of the students reported they were more likely (or more committed) to attend a graduate program. 53% of the respondents said they were more confident about their field of employment, and 9% reported increased uncertainty.

Detailed Summaries of 8 Studies of Undergraduate Research Experiences

Following Table 1, each of these studies is discussed in summary form in the same order they appear in Table 1. More information about qualitative effects is available in these summaries.

Table 1. Summary of Effects on Student Plans & Interest to Do Graduate Work

Study (PI)	**Disciplines**	Institutions Students – response rate	Time period	Gains	No Diff (pre- post studies)	Losses (pre- post studies)
Lopatto	Bio related, mostly	41: R1 to LA 1,135, 74%	2003	**4%**, post B **27%**, deeper^	**57%,** same^	**5%**
Zydney	Engineering	1: U of DE 245, 38%	Grads: 1982-97	30%, post B* 27%, PhD *		
Bauer – like Zydney	All STEM	1: U of DE 986, 42%	Grads: 1982-97	21%->**10%**** 25%->**13%****		
Fitzsimmons Abt Assocs	All STEM REU	Hundreds 1,915 OK%	1987-90	**12+N%**, PhD 17%, deeper^ 53%, more confident re field of emp	**82-2N%** 28% [All deg levels]	**N%***** 19% more unsure of emp field
Russell SRI Internat	All STEM NSF UGR	~700 3,400, 76% 2,100F, 95%	2002, Acad. Yr 2002-03	**43%**, post B **<16+N%**, PhD **6%** MD-->D	**45%** **>84-2N%**	**6%** **N% *****
Hunter, Laursen, & Seymour	Nat Sci	4 LA Cols 76, 100%? 55Fac, 100%	2000	**None or low** Significant % deeper^	**91% -**	**9%** Increased uncertainty
Gonzalez-Espada	Meteorology, Physics	Res & Tchg 38, 100%	2001-05 National Weather Center	Post B: 37% = deeper ^ Career: 32% = deeper ^	**52%** **39%**	11% = lower 29% = lower
Hackett	Engineering	1: Tech Inst (Not named)	1989-90	Coop exp far more influential	Mostly no effect	Not measured-> likely some

^ Deeper means "more likely to attend a graduate program." Overall there was a significant gain.
* These measured effects did not correct for higher GPA. See the next footnote (**).
** GPAs of students with UGR experience were higher, correcting for this bias using a Probit model led to smaller effect sizes. The same correction should be made to the Zydney data.
*** The reported numbers for PhD changes net out the losses from the gains, leaving a net gain of 12% in the Abt study. If the losses were, for example, 5%, then 72% of the REU respondents would be the true "No Difference," and 17% would be the true "Gain."

David Lopatto Study: "Survey of Undergraduate Research Experiences (SURE): First Findings" (2004)

The Sample Described

- 1,135 undergraduates (out of 1,526) who participated in summer UGR programs in Summer 2003 at institutions where at least one program had HHMI sponsorship
- The response rate was 74%.
- Students in HHMI supported programs = 55%.
- Students did their work at 41 institutions
  - 19 Doctoral & Research with 71% of the students
  - 15 Liberal Arts colleges with 23% of the students
  - 7 Master's level institutions with 6% of the students
- Rising seniors = 48%, rising juniors 32%, rising sophomores = 16%.
- Disciplines: Biology = 46%, Biochemistry = 12%, Neurobiology = 10%, Chemistry = 9%, Physics = 6%, Engineering = 5%, rest = 12%.

- Only 13.3% of the students had plans other than graduate school in STEM or medicine:
  - 11.4% had no postgraduate education plans
  - 2.3% did not respond

After the UGR experience:
- 56.5% - unchanged plans for postgraduate education
- 27.0% - confirmation of (deeper) postgraduate education consideration
- 3.5% - plan changed <u>in favor of</u> postgraduate education
- 4.5% - plan changed <u>away from</u> postgraduate education
- 4.5% - still no plans for postgraduate education
- 4.2% - no response regarding the effect of UGR on plans
- Essentially the same pattern for women vs. men, and for minorities vs. Caucasians.

<u>Learning and Maturation Effects of UGR</u>
[Based on a 20 Item survey, using a 5-point Likert Scale: 1 (no gain) to 5 (very large gain)]
- Students who were supported by HHMI funds had slightly higher mean scores on all 20 items.
- All students reported mean values on the 20 items of 3.71.
- Items related to the research process, scientific problems, and lab techniques are rated as the highest gains.
- Those 3.5% deciding in favor of postgraduate education in STEM averaged 4.06.
- Those 4.5% deciding to cancel postgraduate education in STEM plans averaged 3.54.
- The entrants and leavers were closest on 3 items – the highest rated, the lowest rated and the 12^{th} rated item:
  - (1) Understanding the research process (4.13 vs. 4.14),
  - (12) Understanding the primary research literature (3.87 vs. 3.69), and
  - (20) Learning ethical conduct (3.25 vs. 3.02).

Students were asked, what is your overall sense of summer research as a learning experience?
- "Fantastic/ this is the way to learn" 38%
- "Learned a lot" 49%
- "Neutral" 12%
- "Didn't learn a lot" 02%
- "Waste of time" 00%

The Andrew Zydney study: "Impact of Undergraduate Research Experience in Engineering," (2002)
<u>Background</u>
The University of Delaware has operated a formal <u>institution-wide</u> UGR Program since 1980. In addition, the UGR Program runs an <u>institution-wide</u> senior thesis program (where students prepare research proposals, make oral presentations of research in progress, and give an oral defense of their theses.)

In engineering about 30 students per year participate in summer research – usually between sophomore and junior years. Another 40 participate in senior thesis research each year. 77+ (out of 85) engineering faculty participate each year.

An alumni survey was administered to 2,444 alumni of all STEM departments at the University of Delaware from the graduating classes of 1982 through 1997. The intended participants were *deliberately* not informed that one of the reasons for the survey was to determine the effect of

UGR. Students were selected for the survey based on equivalent matching by major and GPA, in order to create equivalent groups who had participated in undergraduate research (or not).

In engineering, 651 graduates were selected; 229 had participated in formal UGR programs based on registrar data. 245 responses were received for a response rate of 38% -- the weakest aspect of this study.
Research design was to match UGR participants with non-participants in the same major and same year of graduation with roughly the same GPA. It turned out that

- 91 responses were from students who registrar records confirmed had done UGR (Average GPA = 3.52)
- 66 responses were from students with UGR experience but not through the formal Program (Average GPA = 3.37)
- 88 responses from students with no UGR experience (Average GPA = 3.33).
- These are high GPA averages but there is a bias in favor of UGR experienced students

<u>Differential transition to graduate programs</u>

- 80+% of UGR students had completed or were enrolled in graduate degree program
- 67% of *other* UGR experienced students had completed or were doing graduate work
- About 50% of non-UGR students had completed or were enrolled in graduate school

How many students ultimately sought a doctoral degree?

- 35% (32) of formal UGR student participants
- 27% (18) of other UGR students
- 08% (07) of non UGR students

While these are quantitatively distinct results there is the possibility that the act of choosing to do UGR (or being picked by a faculty member to do UGR) was a key event influencing students' decisions to do graduate work. In other words, these decisions themselves rather than the UGR experiences may explain part of the differential transition rates in graduate work.

<u>Impact of participation in campus enrichment activities (on student learning and maturation)</u>
Using a 5-point Likert scale, alumni were asked to rate 14 undergraduate activities (5 = very strong, 3 = moderate, 1 = very little benefit)

	Formal UGR Program		**Other UGR Activity**		**No UGR**	
Activity	**Mean**	N, %	**Mean**	N, %	**Mean**	N, %
Internship related to engineering major	4.65	34, 37%	4.77	24, 36%	4.72	29, 33%
Studied abroad *	4.36	10, 11%	3.85	01,	3.35	04, 5%
UGR at U of Del	4.35 **	89, 98%	3.90	64, 97%	NA	0
Senior Thesis	4.18	43, 47%	4.52	11, 17%	3.64	05, 6%
Employed on campus	4.04	44, 48%	3.97	29, 44%	3.83	27, 31%
Employed off campus	3.34	24, 26%	3.97	19, 29%	3.53	24, 27%

* The mean was 4.64 for the total alumni population.
** This mean is significantly higher than "Other UGR Activity" at the level $p < .05$.

- The perceived impact of UGR rises with the number of semesters the student is involved
  - Mean value = 3.64 for 33 who had 1 semester
  - Mean value = 3.9+ for 60 who had 2 semesters
  - Mean value = 4.4+ for 17 who had 3 semesters
  - Mean value > 4.75 for 38 who had 4 – 8 semesters

However, the expectation at the University of Delaware is that students would participate for at least 2 semesters. Thus, the 1-semeseter score may signal some sort of "trouble." Respondents who participated in the overall UGR Program – not just in Engineering -- averaged 3.2 semesters of research. Respondents who engaged in other forms of UGR averaged 2.4 semesters of research experience.

<u>Self-assessment of skills: UGR vs. No Research</u>

The following 5 skills were the highest rated subset of those surveyed

Skill	**UGR exp**	**No Res**
Understand math concepts	4.54	4.44
Use stat or math formulae	4.45	4.51
Think logically about complex material	4.39	4.35
Understand scientific findings	4.36*	3.97
Carry out research	4.30*	3.24

The following skills are those often rated as important

Skill	**UGR exp**	**No Res**
Work as part of a team	3.97	3.86
Develop intellectual curiosity	3.95	3.63
Speak effectively	3.58*	3.03
Possess clear career goals	3.38*	2.84
Know literature of merit in field	3.20*	2.56
Analyze literature critically	2.89*	2.15

* Significant difference ($p < .05$)

Karen Bauer study: "Alumni Perceptions Used to Assess Undergraduate Research Experience" (2003)

This study is an extension of the Zydney, *et al* study. It reports on *all* the alumni surveyed who graduated from the University of Delaware in the 1982 - 1997 period, and found results roughly comparable to Zydney's. There were 986 usable responses from a target group of 2,444 students, who were matched by major and GPA in 2 groups – those who had done UGR or not done UGR, for a response rate of 42%)

- 418 alumni who participated in the UGR Program (91 in Engineering)
- 213 alumni who had engaged in other types of UGR (66 in Engineering)
- 355 alumni with no UGR experience (88 in Engineering)
- A much larger fraction of respondents were women (56%).

<u>Self-assessment of skills comparing Engineering alumni (E) to total alumni (Tot)</u>
<u>& UGR vs. No Research</u>

[**These are the highest rated skill areas for Engineering Alumni**]

Skill	**UGR Eng**	**UGR Tot**	**Difference Eng - Tot**	**No Res Eng**	**No Res Tot**	**Difference Eng -Tot**
Understand math concepts	4.54	3.13	1.41	4.44	3.21	1.23
Use stat or math formulae	4.45	3.19	1.26	4.51	3.17	1.34
Think logically about complex material	4.39	4.04	0.35	4.35	3.93	0.42
Understand scientific findings	4.36*	3.54*	0.82	3.97	3.30	0.67
Carry out research	4.30*	4.47*	-0.17	3.24	3.44	-0.20

The following skills are those often rated as important

Skill	UGR Eng Tot	Difference Eng - Tot	No Res Eng Tot	Difference Eng -Tot
Work as part of a team	3.97 3.55	0.42	3.86 3.47	0.39
Develop intellectual curiosity	3.95 4.24*	-.29	3.63 4.02	-.39
Speak effectively	3.58* 3.69*	-.11	3.03 3.31	-.28
Possess clear career goals	3.38* 3.43*	-.05	2.84 3.08	-.24
Know literature of merit in field	3.20* 3.49	-.29	2.56 3.28	-.72
Analyze literature critically	2.89* 3.67*	-.78	2.15 3.28	-1.13

- Significant difference ($p < .05$)
- Shaded values => lower score than for Engineering alumni.

What immediate stands out is that four of the five skill areas rated most highly by engineering alumni were substantially less developed for alumni graduating in other fields. The exception is the ability to "carry out research," which was slightly higher for non-engineering graduates. This result holds for both students participating in the formal UGR Program and for those who did not do UGR. The two skill areas where UGR provided significantly higher skill to engineering students also did so for students in other majors.

Conversely, in the six skill areas often considered to be important correlates of research experience, engineering alumni scored higher only in one area – teamwork. In the other five areas the non-engineering alumni scored moderately higher in 3 and substantially higher in one (the ability to "analyze literature critically"). This result holds for both students participating in the formal UGR Program and for students who did not. Comparing these 6 skill areas to matched students who did not engage in research, the UGR Program participants were significantly higher in 4 areas for both groups – Engineers alone, and all alumni.

Interestingly, and compatible with other studies, "Possess clear career goals" was rated on the low side by all groups.

<u>Differential transition to graduate programs</u>

- 80% of UGR students had completed or were enrolled in graduate degree program (same in engineering)
- 71% of *other* UGR experienced students had completed or were doing graduate work (67% in engineering)
- 59% of non-UGR students had completed or were enrolled in graduate school (50% in engineering)
- Controlling for the positive effect of GPA, the probability of students with a 3.5 GPA pursuing graduate degrees was 67% for formal UGR alumni and 57% for alumni with no research experience, a significant difference.

How many students ultimately sought a doctoral degree?

- 33% of formal UGR student participants (vs. 35% in engineering alone)
- 20% of other UGR students (vs. 27% in engineering)
- 08% of non UGR students (vs. 7% in engineering)
- Controlling for the positive effect of GPA, the probability of students with a 3.5 GPA pursuing doctoral degrees was 43% for formal UGR alumni, 36% for alumni with other research experiences, and 23% for alumni with no research experiences.

<u>Two Assessments of NSF's REU (and other) Undergraduate Research Programs</u>

1. Stephen Fitzsimmons 1990 evaluation study of the NSF REU Program (Abt Associates)

This covered the first 3 years of the REU Program – 1987-90. Its methodology consisted of surveying both students and faculty sponsors of REU Projects, both at sites – special summer programs created for faculty guided undergraduate research for ten weeks periods -- and within regular NSF research projects as supplements. The surveyed students were 41% female and 10% of the REU participants were from racially or ethnically under-represented demographic groups. Less than 20% of the surveyed students were engineering majors. The study concluded that:

- "The findings suggest that the REU program is achieving its principal objectives of simulating promising undergraduate students' interest in S&E fields, and positively influencing their decisions to enter graduate school, earn doctorates, and pursue S&E careers." (Page iv)

- "The majority of students participate in the REU program in order to find out if being a researcher, attending graduate school, and/or their planned field of science or engineering was right for them." (Page iv) Based on the detailed contents of the evaluation, this second conclusion appears to be overstated. The pre- and post-participant characteristics indicated that (Page v):
    - The percentage of participants planning to earn doctorates rose from 45% to 57%.
    - Those students planning to end their formal education with a bachelor's degree declined from 26% to 5%.
    - Those who stated they were somewhat ($1/3^{rd}$) or highly ($2/3^{rds}$) likely to enroll in a graduate program rose from 75% to 92%. (Those planning to enroll at the completion of their bachelor's rose from 66% to 73%.)
    - Those participants with a high degree of certainty about their major field of study rose from 65% to 71%. (More students participated between their junior and senior years – about 65% -- that between their sophomore and junior years.)
    - These effects were roughly the same for women and under-represented minorities as for other students.

- Student and faculty PI evaluations of the REU activities were generally consistent, which is reassuring. (Page 8) Both agreed that the following activities were beneficial (Page viii):
    - Seeing how research is really done
    - Conducting experiments
    - Working on independent research projects
    - Time spent working with REU advisors (> 75%)

Students reported the highest levels of satisfaction with learning the nature of the job of a researcher, specific techniques or procedures, substantive knowledge of the field, and the basics of the scientific method. (Page viii)

Students who applied for REU participation because "they loved this field of research and wanted to do real work in it" were generally the most satisfied with their experiences. Also, students who worked on independent projects were likely to be more satisfied, but also were more likely to rate the projects as too challenging. (Page ix)

The study recognized that its greatest weakness was the lack of a control group. However, its findings are in range of most of other studies – although at the high end of that range. There are several bias issues that need to be recognized. One is that three-fourths of the REU projects, particularly "site" projects, actively recruit their students. Site projects also made strong efforts to recruit women and minority students. It is likely that active recruitment will both reach the best students (particularly when it is by word of mouth) and enlarge the pool of applicants, allowing the PI to pick the best students. This means that the efficacy of undergraduate research is not being tested much among average students.

2. Susan Russell, *et al*, "Evaluation of NSF Support for Undergraduate Research Opportunities," *Final Report to the NSF*, SRI International (June, 2005).
This assessment covered research projects that operated in the summer of 2002 or the 2002-2003 academic year. It included both the sites and supplements projects in the REU Program and

- NSF sponsored research centers with significant UGR components
- RUI projects
- HBCU-Undergraduate Program projects (HBCU-UP)
- Tribal Colleges & Universities Program (TCUP)
- Louis Stokes Alliance for Minority Participation Program (LSAMP)
- Cooperative activities with the Dept. of Energy's education programs

This is the most comprehensive study of the effects of UGR. Overall, the evaluation included more than 1,000 NSF awards and students from more than 700 institutions. It is possible that some of these sites included average students in research:

- 57% had undergraduate GPAs in the 3.5 to 4.0 range
- 28% had GPAs in the 3.0 to 3.5 range
- 15% had GPAs below 3.0

The survey covered 4,500 undergraduates, 2,200 faculty mentors and principal investigators, and 800 graduate student or post-doc mentors. The response rate ranged from 76% of the undergraduates to 95% of the PIs. This is the best response rate reported in empirical studies.

The surveyed faculty members (PIs) claimed that they were not just selecting students who were likely to go on to teaching and research careers in STEM fields. Almost all agreed "research is a good experience for undergraduates, regardless of their decisions about career or advanced degrees." (Page ES-3) When asked if "UGR was more valuable for students who will pursue research or teaching careers," the mentors responded:

- Agree or agree somewhat (51%)
- Disagree or disagree somewhat (49%)

Thus, half the faculty mentors thought UGR was good for *al*l students but better for those pointing towards careers in STEM fields.

The demographic breakdown of student participants was substantially more diverse than those who participated in the REU experiences in the late 1980s. (Of course the inclusion of LSAMP, HBCU-UP and TCUP virtually guaranteed this greater diversity, which is what these programs were *intended* to do.)

- 31% were from under-represented minority groups (vs. 10% for the earlier REU assessment)
- 8% were from Asian groups
- 61% were non-Hispanic white students

Perhaps the most powerful finding was that **"Degree expectations of about half of the students were either raised or shifted from medicine/ law to STEM…"**

- Raised expectations (43%) [As much as 16 percentage points of this gain could be to PhD level; see table below.]

- Raised expectations were highest in engineering (58%) and life sciences (54%); the latter gain was due in part to the decline in MD expectations.
- The highest raised expectations were for Hispanics (59%)
- Horizontal shift to STEM; typically MD to PhD (6%)
- Unchanged – PhD expected before and after UGR experience (21%)
- Unchanged - not PhD (20%)
- Lowered expectations, or shifted away from STEM (6%)
- Response unclear (4%)

As a complementary metric, students were also asked about the highest degree that they expected to earn before and after the UGR. The following table reports their responses, which are curiously incomplete (about 1/4th of the respondents did not answer).

Highest Degree Expectations of Undergraduates participating in UGR, Pre- & Post- UGR

Degree Expectations	Pre-UGR	Post-UGR
BA or BS	25%	05%
MA or MS	18%	21%
PhD or Science D	26%	45%
MD	10%	05%
No response	21%	24%

<u>The Effects of the Research on Students</u>

- Increased confidence was the most strongly related to increased interest in careers and raised degree expectations.
- Increased confidence was derived from
  - Participating in a variety of research-related activities
  - Gaining independence
  - Seeing the bigger picture underlying the research
  - Having "sufficient contact" with the faculty mentor
  - Being involved in the project design
- Positive outcomes for students were related to two pre-UGR conditions
  - Personal enthusiasm for doing research (based on 3 items) [In particular, students with high levels of enthusiasm pre-UGR were most likely to claim increased interest in STEM careers post-UGR.]
  - Need for help with an academic or career decision (based on 4 items)

- For demographic subgroups same sex faculty mentors did not seem to matter, nor did same race or ethnicity faculty mentors. This finding is at variance with other research that found that sex and race / ethnicity of the mentor was important. The study suggested it might be due to self-selection of students to projects with mentors they found appealing.

Anne-Barrie Hunter, Sandra Laursen, and Elaine Seymour study: "Becoming a Scientist: The Role of Undergraduate Research in Students' Cognitive, Personal, and Professional Development" (2006 draft)

- This is an in-depth study of undergraduate research experiences of students at four liberal arts colleges. This draft paper discusses findings from only the first round of student and faculty data sets. The authors plan follow-up studies.
- The study sought answers to 4 questions – what faculty observers considered student gains to be, what students identify as the benefits of UGR – immediate and longer term, the processes by which gains to the students are generated, the benefits and costs to faculty, and **what (if anything) is lost by students who do not participate in UGR.** This review reports mainly

on the character of student gains. However, this preliminary study does not report on the comparative data obtained from the control group, so it s value is limited.

The sample

- 55 faculty advisors were interviewed in the summer of 2000.
- 76 students who were engaged in UGR in the summer of 2000 (predominantly rising seniors) were extensively interviewed. [They were interviewed a second time just before graduation in the spring of 2001 (N = 69) and a third time as alumni in 2003-04 (N = 55).]
- A comparison group of 62 students who had not participated in UGR were interviewed on the same schedule. [There was a substantial loss of response rate in 2003-04 (N = 25).]

The selection process

- Typically the application process was competitive, even for students invited to participate.
- Faculty sorted preferences and ranked students research preferences, following up with interviews to assure a good match on both research focus and personal chemistry.
- Typically decisions were made on a greater good group basis, in order to get the largest number of good matches.
- Typically a faculty research advisor worked with 2 students; many worked with 3 or 4.

Student research

- The description in this paper suggests that the design of student research projects is critically important to success.
- Each student project was open-ended but defined in order to give the student a reasonable chance of completing it in the short time frame and producing useful results.
- It is crucial to select a project appropriate to the student's "level" and interests, in order to stretch their capacities but not beyond reason.
- Initial activities included
    - Orienting students to the lab and the project
    - Providing relevant background information and literature
    - Teaching the various skills and instrumentation necessary to work effectively, which required faculty mentors and to be flexible and willing to be facilitators of student learning
    - Use of mini-lectures
- Subsequent activities
    - Regular contact but not side-by-side working every day
    - Weekly meetings to ensure things were progressing as expected
    - Increasingly faculty could focus on other tasks while students worked more independently
    - Seminars and field trips were often planned
    - Typically, at the end of the summer student researchers attended a campus wide UR Conference where they presented posters and shared their research with their peers, faculty members, and institution administrators.

- Basic findings regarding impact on students are reported as a percentage of all statements (1,230) rather than as a percentage of all students (76). [There were 16 responses per student.] Statements are coded after a structured, but open-ended interview.
- The frequency of student reported gains were:
    - Personal-professional gains (Confidence) (28%)
    - Thinking and working like a scientist (28%)
    - Gains in various skills (19%)

  - Clarification / confirmation of career plans – including plans for graduate school (12%)
  - Enhanced career / graduate school preparation (9%)
  - Shifts in attitudes to learning and working as a researcher (4%)
- Faculty reports essentially agreed with the students but also identified a category "becoming a scientist (20%) as opposed to "personal-professional gains."
- In response to this category, the student data were re-classified to include this as a category.

<u>Interesting findings</u>
Few students developed the capacity to generate and frame research questions that can be approached by alternative scientific methods, or a "complex epistemological understanding of science." (Page 14) The only two other valid studies also found this to be true. Thus there is a definable limit on the higher order thinking skills that are developed through UGR.

Contributing to the notion that students are learning to think like scientists, over half of faculty observations described changes in student conduct and manner, exhibiting more curiosity and initiative, becoming less fearful of being wrong, and being more willing to take risks. (Page 16)

The majority of students' observations on becoming a scientist (57%) referenced increased confidence. (Page 19)

Faculty put a lot of effort into arranging opportunities for students to make presentations. (Page 23) But "few students were involved in assisting their research advisors in writing scholarly articles. Indeed, faculty discussed publishing co-authored papers as a benefit that 'comes later' or beyond graduation." (Page 32) [In fact students may have graduated by the time faculty publish the research the students aided.] "Helping students to learn professional writing skills requires more time and effort than is possible during the available 10 weeks." (Page 32)

On the other hand, gains in lab techniques and learning instrumentation were noted among the highest skill gains by both faculty and students. …Students were obliged to quickly learn how to do things." (Page 32)

<u>Findings regarding increased interest in graduate school in STEM</u>
A much higher percentage of observations made by faculty (57%) than by students (12%) in this category were about "students' increased interest and enthusiasm for research or the field of study." (Page 26) The authors believe that this is because these faculty advisors have a "history of seeing many students extend their summer UGR into the academic year and / or for several more summers." (Page 26)

Thirty-six percent of student observations and 20% of faculty observations in this category described the UGR experience as instrumental in helping students find out whether grad school and a career in science research would be a good choice. (Page 27) Seven of the 76 respondents decided that research was not for them. (Page 27) "In summary, for this group of students at liberal arts colleges, we did *not* find that a UGR had prompted their decision to go to graduate school. …Most had planned for and anticipated a graduate school education. …The role of UGR was to increase their interest in and probability of going on to graduate school, …and to clarify which field of interest to pursue." (Page 28)

Most of the students' statements for engaging in UGR (71%) 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." (Page 30)

There was a “low number of student observations on career clarification, reflecting students’ ongoing uncertainty: as rising seniors, and at time in life when the world seems wide open, students were still unclear about what they might like to do professionally.” (Page 38)

Gonzalez-Espada study: "Evaluation of the Impact of the National Weather Center REU Program Compared with Other Undergraduate Research Experiences" (2006)

The purpose of this paper was to inform the atmospheric science community about a partial evaluation of the National Weather Center's REU Program, which addressed three questions:

- Is there a statistically significant difference in graduate school plans for the 2001-2005 students before and after the summer UGR experience?
- Is there a statistically significant difference their career plans before and after?
- Is there a statistically significant difference in their perceptions of their potential for doing scientific research before and after?

This paper is of interest partly because atmospheric science research is not restricted to traditional scientific positions. (Page 2)

<u>The sample</u>
Data were collected from 38 REU participants from the period 2001 – 2005. These students were

- 56% female
- 10% under-represented minority students
- 87% juniors and seniors
- 90% physics and meteorology majors
- Evenly split between research and teaching institutions

<u>The survey</u>
Students were surveyed before and after the REU experience about their plans for attending graduate school, their career plans (are they well defined?), and if they saw themselves becoming research scientists. Using a 5-point Likert scale the following results were reported

- Graduate school plans: The mean score rose from 4.46 to 4.62 with a larger rise in the median from 4.25 to 5.00. 11% of the respondents lowered their score and 37% raised their score. Based on a Wilcoxon matched-pairs signed-ranks test, this was a significant gain at the "$p < .05$" level.
- Well-defined career plans: The mean score dropped from 3.02 to 2.97 and the median remained at 3.00 before and after the REU experience. 29% of the respondents lowered their score and 32% increased their score. This was not a significant result.
- Becoming a research scientist: The mean score fell from 3.83 to 3.67 and the median remained at 4.00. 28% of the respondents lowered their score and 17% raised their score. This indicates that the NWC REU program did not raise students "self-efficacy on becoming research scientists."

The lack of significant results in clarifying career plans was explored qualitatively. "Several students mentioned being overwhelmed by the number of possible career options with meteorology they discovered through the summer." Students were excited about recently discovered options, which the authors called "happy confusion."

The Edward Hackett study: "Industry, Academe, and the Values of Undergraduate Engineers" (1992)

This is a somewhat complex study of how the "values" (including possible career preferences) of undergraduate engineers are both shaped by and influence their choice of undergraduate experiences. An important undergraduate experience for engineering majors in some institutions is participation in cooperative education programs. These place engineering students in industrial jobs for a period of approximately 6 months. Another important experience is undergraduate research (UGR). Some engineering programs have developed programs that place students in structured research experiences (on campus) under the supervision of a faculty member.

This study examined engineering students at an unnamed technical college with a coop program and an undergraduate research program. Some of the research projects were located within research centers while others were affiliated with traditional faculty research projects in departmental labs. The college had 4,400 undergraduates and 1,600 graduate students in the spring of 1990.

Coop experiences and UGR have the potential to have significant influence on students in comparison to other influences. This study explored how the impact of these college experiences on students when "background" characteristics of the students are taken into effect -- characteristics such as gender, parents' occupations and educational attainment, non-college reference groups -- the influence of family and friends -- and the students initial *personal* interest in career choices.

The study sought to address three questions. The first two have some relevance for this review.
1. Who chooses to participate in coop or research programs? Why do they participate?
2. What skills and abilities do students use during the programs, and how does participation influence students' career plans?

<u>The sample</u>

Two samples were drawn – a one-third probability sample of the registered students in the spring 1990, and a one-half sample of sophomores, juniors, and seniors who participated in coop programs in the spring 1989 or the fall 1989 (and were registered in the spring 1990). These samples formed a pool of 972 engineering students. Mailed questionnaires yielded 436 usable responses – a response rate of 45 percent.

Most freshmen and sophomores do not participate in coops or research. More than 90% of freshmen and sophomores were non-participants in coop or UGR experiences. However, 56% of the juniors and 79% of seniors participated in one of these or both of them. Overall, 71 students had participated in UGR, 74 in a coop program, 29 in both, and 257 (59%) in none. Women accounted for only 19% of these surveyed students, which is representative of their presence in engineering.

Students choosing UGR versus coop (or none) had very distinctive characteristics as a group. On the basis of parents' occupations and parents' highest education – it was coop-participating students that were drawn (on average) from the highest socio-economic class. Students selecting UGR were drawn, on average, from the lowest socio-economic class, and non-participating students were in the middle. As noted in the study:

- "Students whose parents had no more than a high school education (20%) are 2 to 3 times more likely than others to participate in UGR but only half as likely as others to take a coop position."

- The study suggested, “The observed results are consistent with a different lesson passed from parents to children. Perhaps college educated parents realize that a college education alone is not sufficient to ensure a good career [in engineering] and that augmenting a college degree with work experience provides a valuable advantage in the job market.”

Student identified necessary abilities

In comparing the students' ratings of 11 abilities that may be needed to succeed in a coop or UGR experience (on a 5-point scale), the only significant differences for students participating in only one of these experiences were

- Work with others (coop = 4.3, research = 3.3)
- Work with hands (research = 3.4, coop = 2.6)

Students who did both coop and research work were more discriminating in rating these abilities, perhaps rightfully so. In addition to agreeing with the above two rankings, these students also indicated that coop work was significantly more demanding in terms of

- Creativity (4.0 vs. 3.4)
- Writing/ speaking skills (3.9 vs. 2.7)
- Working rapidly (3.8 vs. 2.8)
- Working under pressure (3.8 vs. 2.9)

Just below the highly significant threshold, “dual” students also rated coop experiences as more demanding in terms of

- Reasoning skills and
- Organizational skills

This study suggested, “Coop jobs [available through this technical college] immerse students in the world of industry in a way that exercises their intellectual, interpersonal, and communication skills." These ratings suggest that students are "skilled participants in the work." "So involved are they in the work that deadlines and pressures are felt acutely." On the other hand, "research positions afford students the academic experience of less pressure, less collaboration, and greater hands-on experience with apparatus and materials.”

Influences on career choice

- All students asserted that their personal interests are the primary guide of their career choices, and are much more important than advice from family and friends (4.5 vs. ratings < 3.0)
- Students experiencing coop programs rated them very influential (4.5), far more so than classroom experience (3.4)
- Students participating in UGR programs rated them only on par with classroom experiences (3.4 each)
- Students experiencing both research and coop programs, rated coop experiences even higher (4.8), and research and classroom experiences lower (2.9 and 3.2)

The study concluded that both coop and UGR experiences were significant and influential but (at least at this college, in engineering) the coop experience was substantially more influential.

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