Using Pre-College Research to Promote Student Success and Increase the Number of Science Majors

Undergraduate research is an American invention (Doyle 1992, Hunter 2007). Opportunities to participate in undergraduate research have been shown to increase students’ understanding of science, confidence in their ability to conduct scientific research, awareness of PhD training, and interest in obtaining a PhD (Bauer and Bennett 2003, Hunter, Laursen and Seymour 2007, Russell, Hancock and McCullough 2007, Seymour et al. 2004). In addition, research has demonstrated that mentors who combine enthusiasm with individual attention to their undergraduate researchers are essential for enhancing the most positive outcomes of undergraduate research (Cech 1999, Hunter, Laursen and Seymour 2007, Russell, Hancock and McCullough 2007). In fact, the SRI International study of undergraduate research commissioned by NSF surveyed close to 15,000 respondents, and the authors concluded that “the inculcation of enthusiasm is the key element—and the earlier the better” (Russell, Hancock and McCullough 2007). Yet fewer research opportunities exist for first-year students than for juniors and seniors (Hurtado et al. 2008). We report here on a project that has been highly effective in encouraging and retaining science and mathematics majors at Hamilton College. In this project we brought students who had just finished high school into a research laboratory for a five-week research experience prior to matriculation at Hamilton. Students participated in research projects in eight fields—computational chemistry, organic chemistry, inorganic chemistry, physical chemistry, biochemistry, chemical physics, neuroscience, and physics.

Outline of Program

Hamilton College is a highly selective liberal-arts institution. The main idea of the pre-college research program was to immerse students in a summer research project between graduation from high school and the beginning of their freshman year at Hamilton, with the goal of increasing the number of students who majored in a STEM (science, technology, engineering, and mathematics) discipline. This summer bridge program was designed to address intellectual as well as social needs. The model was based on learning communities, which have been shown to promote coherence and a sense of community among group members, increase academic achievement and retention, and encourage continuity and the integration of diverse curricular and co-curricular activities.

We recruited students who we believed were seriously interested in pursuing a scientific career. The program was advertised through our admissions office, and additional specific and targeted recruitment efforts were made to female students. Each student applicant was provided with information on the research projects of each faculty member participating in the project. The application process consisted of a short questionnaire requesting information on the students’ scientific background and experiences, career aspirations, academic profile, extracurricular interests, and other relevant information. The students who seemed best suited for the program were interviewed, first by the principal investigator, George Shields, and the summer science research coordinator, Leslie North, and later by the faculty members themselves to assure the best match between student and faculty member. Students were selected from all ability ranges represented in the Hamilton College application pool, in an attempt to track the effectiveness of this program for students with less preparation prior to college than the best-qualified students. The summer science research coordinator worked closely with the students to help them with logistical issues and was a vital member of the project team.

Each successful applicant worked for five weeks in the first summer with his or her faculty mentor and was paid a stipend of $350 per week from a grant received from the National Science Foundation’s Science Talent Expansion Program (NSF-STEP) funds. The students lived in a special housing unit, with two upper-class science students serving as resident advisors, resulting in a strong sense of community among the participants. The STEP budget for this grant was modest; Hamilton contributed $10,000 in matching funds for the first year of the program to fund the development of recruitment materials and for lunches, publications, and a faculty-development workshop. Ongoing support for special events with STEP participants was also provided.

The college provided a second summer of research, for 10 weeks, for all STEP students who maintained their intention to declare as science majors. Room and board was also partially subsidized for all summer research students; room and board ranged from $35 to $50 per week depending on the living situation. Faculty were not paid to take STEP students into their labs, and most used the opportunity to train students who became excellent researchers by the end of the second summer. Many faculty members supported their STEP students with their own grants or with college money for another summer or two, thus enhancing the students’ understanding of the
scientific method and increasing the scholarly output from the faculty member’s laboratory.

Because we believed that even highly prepared and motivated incoming students lack some of the training and laboratory skills that our matriculated students may have already mastered, a pre-summer workshop was offered by the principal investigator to all faculty members participating in the project. The workshop included an informal discussion with students who had done research prior to their freshman year. They helped highlight the most important aspects of becoming integrated into a research lab directly after high-school graduation. (The complete proposal and timeline, as well as the final project report, are available from the PI upon request, george.shields@bucknell.edu)

Measuring Results
In a pilot study of the project’s effectiveness, we initially included two students from the class of 2004, three from the class of 2005, and 10 from the class of 2006. Of these 15 students, 12 majored in math or science. With funding from the Dreyfus Foundation and the NSF-STEP program, we brought in 13 students from the class of 2007, 11 from the class of 2008, 10 from the class of 2009, and 10 from the class of 2010. We show below the effectiveness of this program for encouraging and retaining science and mathematics majors.

To evaluate progress towards the stated goals of the pre-freshman summer research program, the various student outcomes among participants were measured for the combined entering cohorts of 2003, 2004, 2005, and 2006 (entering classes of 2007, 2008, 2009, and 2010). These analyses were conducted using an intervention group (program participants) and a control group (non-participants who had applied for the program). By using this control group we minimize self-selection bias in the analysis since these students were interested enough in science to apply for the program and demonstrated a level of desired engagement equal to that of the program participants. We also address bias in our results by conducting a regression analysis, where we controlled for applicant rating (as determined by Admissions) and SAT score in relation to cumulative grade-point average.

Analysis was conducted on three specific outcomes for the students who participated in the summer research program—subsequent selection of a science major, retention, and cumulative grade-point average. Selection of a science major was analyzed because it fit in with the specific goals of the program. The overall “success” variables of retention and grade-point average were analyzed to demonstrate the impact the program had on the overall student experience.

Selection of Major
As shown in Table 1, a higher percentage of program participants (73.8 percent) selected a science or mathematics major (in biochemistry, biology, chemistry, computer science, environmental studies, geoarchaeology, geology/geoscience, neuroscience, mathematics, or physics) than non-participants (59.3 percent). The difference was significant at the p < 0.10 level.

Retention
The difference between the two groups—program participants versus non-participants—in students who have permanently withdrawn from Hamilton does not reach a level of significance (p < 0.05), but the fact that only two participants in four years has left shows that retention may be a prominent outcome of the program. As shown in Table 3 below, 10 students, or 11 percent, of the non-participants had left Hamilton (for an 89 percent rate of retention) while fewer than 5 percent of the summer research participants had left (95 percent retention). The long-term institutional retention rate (6-year graduation rate) for Hamilton is 88 percent.

If we include the students who entered the pilot program run by the principal investigator in 2000, 2001, and 2002 (classes of 2004, 2005, 2006), we have an additional 15 students who entered Hamilton as participants in summer research prior to matriculation. All 15 graduated and 12 of those 15 (80 percent) majored in science or math. Thus the overall retention rate for the 57 students who participated in pre-college science research is 97 percent. We note that of the two students who transferred, one transferred to the college where she spent her senior year of high school; the other encountered personal problems and the family decided he should attend college closer to home.

Cumulative Grade-Point Average
To measure the relationship program participation had with student grade-point average, a multivariate regression analysis was conducted. Other independent variables that have an influence on student academic success—SAT, applicant rating, gender, and ethnicity—were included in the model. As shown
Breaking out selection of major by gender and ethnicity shows that, while males were more likely to select a science/math major than females, the difference did not rise to a level of statistical significance. There was also not a significant difference in this choice between students of color and non-students of color within those two groups (see Table 2). This is in accord with previous research (Hyde and Linn 2006, Russell, Hancock and McCullough 2007).

Table 1. Subsequent Science/Math Major Declaration by Program Participation Status

<table>
<thead>
<tr>
<th>Major/Math major</th>
<th>Participation status</th>
<th>Non-participant applicant</th>
<th>Program participant</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Count</td>
<td>% within Status</td>
<td>Count</td>
<td>% within Status</td>
</tr>
<tr>
<td>Non-science/math major</td>
<td>33</td>
<td>40.7%</td>
<td>11</td>
<td>26.2%</td>
</tr>
<tr>
<td>% within Status</td>
<td>35.8%</td>
<td></td>
<td>35.8%</td>
<td></td>
</tr>
<tr>
<td>Science/math major</td>
<td>48</td>
<td>59.3%</td>
<td>31</td>
<td>73.8%</td>
</tr>
<tr>
<td>% within Status</td>
<td>64.2%</td>
<td></td>
<td>64.2%</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>81</td>
<td>100.0%</td>
<td>42</td>
<td>100.0%</td>
</tr>
<tr>
<td>% within Status</td>
<td>100.0%</td>
<td></td>
<td>100.0%</td>
<td></td>
</tr>
</tbody>
</table>

\(\chi^2 (1, N=123) = 2.55, p = .08\)

# in Table 4, applicant rating had the strongest relationship \((p = 0.004)\) with the dependent variable, GPA, but program participation was almost as strong \((p = 0.009)\) when the other variables were held constant. It is important to note that program participation had a strong relationship with college GPA even when applicant rating—a measure of the student’s overall background and preparation—was controlled for.

## Summary of Program Results

Combining the 15 students in the pilot program run by the principal investigator prior to NSF-STEP funding with the 42 students who participated in the Dreyfus/NSF-STEP program in the summers of 2003, 2004, 2005 and 2006 (classes of 2007, 2008, 2009, and 2010) reveals that 75 percent of the students who participated in research prior to their first year of college wound up majoring in mathematics or science. Comparing the NSF-STEP entering cohorts of 2003, 2004, 2005 and 2006 to the control group of students who applied for the program and were not selected, we see a difference in the selection of a math or science major significant at the \(p < .01\) level. Of the participants in the NSF-STEP program, 73.8 percent selected a math/science major, while 59.3 percent of the control group selected a math/science major. Breaking out selection of major by gender and ethnicity shows that there was no statistical significance in the differences between the groups, although the
samples were relatively small, making the findings somewhat inconclusive.

The finding on overall retention at Hamilton is very interesting. The difference between the NSF-STEP and control groups in students who have permanently withdrawn from Hamilton does not reach a level of significance ($p < 0.05$), but the fact that only two participants in four years have left Hamilton shows that retention may be a major benefit of the program. The overall retention rate calculated for all students who have participated in the summer program to date is 97 percent. The long-term institutional retention rate (6-year graduation rate) at Hamilton is 88 percent, so an increase of almost 10 percentage points helps achieve an important institutional goal.

Participants in the program also had an advantage over non-participants in average GPA of about 2.5 points (on a 100-point scale), when holding other student variables constant, such as admissions rating, SAT scores, race, and gender. Combined with increased retention, this shows that the program had a positive effect on two key measures of student success.

The reason this program worked well in promoting students’ success is illuminated by students’ responses to a survey they completed at the end of their summer’s research, as well as from recent research on student retention and success. From the surveys we learned that students’ goals as they entered the program were to meet their future professors; learn to understand the campus and make friends; gain lab experience to further their interests in science; and have fun and earn money. At the end of the summer, students reported that they felt that the primary benefits of the summer research experience were both academic and social, because they were able to continue learning about scientific subjects such as biology, neuroscience, and chemistry, as well as getting acquainted with fellow participants, upperclassmen, and the Hamilton community and campus. One student reported that it is “both academic and

### Table 3. Retention by Program Participation Status

<table>
<thead>
<tr>
<th>Permanently Withdrawn</th>
<th>Applicant Status</th>
<th>Count</th>
<th>% within Status</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Non-participant</td>
<td>81</td>
<td>89.0%</td>
</tr>
<tr>
<td></td>
<td>Program participant</td>
<td>42</td>
<td>95.5%</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>123</td>
<td>91.1%</td>
</tr>
<tr>
<td>Yes</td>
<td>Count</td>
<td>10</td>
<td>11.0%</td>
</tr>
<tr>
<td></td>
<td>% within Status</td>
<td>4.5%</td>
<td>8.9%</td>
</tr>
<tr>
<td>Total</td>
<td>Count</td>
<td>91</td>
<td>100.0%</td>
</tr>
<tr>
<td></td>
<td>% within Status</td>
<td>100.0%</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

$\chi^2 (1, N=135) = 1.52, \ p = .18$

### Table 4. Summary of Regression Analysis for Selected Independent Variables and Cumulative Grade Point Average

<table>
<thead>
<tr>
<th>Model</th>
<th>B</th>
<th>SE</th>
<th>b</th>
<th>t</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Participation Status</td>
<td>2.565</td>
<td>0.967</td>
<td>0.212</td>
<td>2.653</td>
<td>0.009**</td>
</tr>
<tr>
<td>Applicant Rating</td>
<td>1.357</td>
<td>0.460</td>
<td>0.290</td>
<td>2.949</td>
<td>0.004**</td>
</tr>
<tr>
<td>SAT</td>
<td>-2.788E-03</td>
<td>0.003</td>
<td>-0.084</td>
<td>-9.66</td>
<td>0.336</td>
</tr>
<tr>
<td>Gender</td>
<td>7.191E-02</td>
<td>0.005</td>
<td>0.006</td>
<td>0.079</td>
<td>0.937</td>
</tr>
<tr>
<td>Ethnicity</td>
<td>-3.674</td>
<td>1.499</td>
<td>-0.228</td>
<td>-2.451</td>
<td>0.016*</td>
</tr>
</tbody>
</table>

N=123, $R^2=.256$

* significant at the $p<.05$ level

** significant at the $p<.001$ level
social [because] I learned both about organic chemistry and made new friends.”

This program allowed students to integrate important social aspects of college transition, namely the ability to bond closely with a few peers and a few faculty members early on, with a rigorous scholarly activity within their realm of interest. The importance of this combination cannot be overstated, and it is an example of the highly personal nature of undergraduate research that turns students on to science (Cech 1999). The model presented in this paper is relatively easy to implement at a variety of different institutions; all that is required are research-active faculty members ready to work with enthusiastic incoming undergraduates in their research laboratories.

Adaptation of Program for Public Universities
At the end of the five-year program, a decision was made in the dean’s office to support different initiatives, rather than to institutionalize the STEP project. Shortly thereafter, the PI left to become dean at a public institution in Georgia, Armstrong Atlantic State University (AASU), and has worked with the faculty there to adapt what worked at a highly selective private liberal-arts college to a non-selective state university, also using a STEP grant. Student performance in STEM fields in Georgia is well below national averages, and the average combined SAT score of incoming freshman at AASU is 1000.

Additional components added to the program at Armstrong Atlantic include combining the best practices of learning communities with the summer bridge-program approach. The learning communities are built around three components: a pre-freshman bridge to university life that includes a five-week, undergraduate-research learning community, as in the Hamilton model; a week-long, skills-enhancement program in applied math; and a year-long learning community that culminates in a second, 10-week summer research project. Ongoing math and science tutoring during the academic year is a critical part of the program. Implementation of the AASU STEP proposal (available from George Shields) was coordinated with the first comprehensive summer undergraduate research program at Armstrong Atlantic (Shields 2010).

Acknowledgements
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References

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George Shields was the founding dean of the College of Science and Technology at Armstrong Atlantic State University. He holds a PhD in physical chemistry from Georgia Tech and has published 40 papers with 42 undergraduates. He has mentored 95 undergraduates in research projects since 1989, at Lake Forest College, Hamilton College, and Armstrong Atlantic. He has recently assumed the position of Dean of the College of Arts and Sciences at Bucknell University.

Gordon Hewitt is assistant dean of faculty for institutional research at Hamilton College. He holds a PhD in higher-education administration from the University of Wisconsin-Madison and has worked in institutional research for 11 years at Hamilton and at Tufts University.

Leslie North is the coordinator of health-professions advising and coordinator of summer science research at Hamilton College. She has 25 years of experience in college admissions and student retention.