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Recommended Citation

D. Newman, L.K. Wright, H. Sweet (2010) A STRUCTURED UNDERGRADUATE RESEARCH PROGRAM THAT TRAINS AND PREPARES STUDENTS FOR POST-GRADUATE EDUCATION AND SCIENTIFIC CAREERS, ICERI2010 Proceedings, pp. 5010-5019.

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A STRUCTURED UNDERGRADUATE RESEARCH PROGRAM THAT TRAINS AND PREPARES STUDENTS FOR POST-GRADUATE EDUCATION AND SCIENTIFIC CAREERS

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Abstract

In this paper we present a model for a structured, rigorous, undergraduate research program which has been developed and successfully implemented for six years at the School of Biological and Medical Sciences at the Rochester Institute of Technology (RIT) for students interested in pursuing long-term independent research experiences. The Research Scholars Program (RSP) includes crucial elements of preparation, presentation, and publication into the undergraduate research experience and helps students meet the National Science Foundation's four "Undergraduate Competencies" that are crucial for scientific literacy.

Since 2005 between five and thirteen students per year have successfully completed RSP (56 to date). Upon college graduation, more than half of these students enrolled in graduate or medical school at a Top American Research University. Current students, alumni and faculty were surveyed about their experiences: "Reading and critiquing scientific literature", "Learning to work independently", "Preparing and giving oral presentations" and "Writing initial research proposals and final papers" were considered highly valuable components of the program.

Design and implementation of such a program does not require significant additional departmental or institutional financial support but does require resources in terms of faculty leadership and mentorship. Thus, RSP could easily be modified or adapted to fit into any undergraduate college setting and could be expanded into other STEM disciplines. In this paper we discuss the mission, structure, components and challenges of the RIT Research Scholars Program and present data supporting the benefits of this program to participating undergraduate students.

Keywords: Undergraduate Research, Undergraduate Education, Scientific Literacy, Science Writing.

1 INTRODUCTION

Numerous, well documented studies have reported benefits to undergraduate students involved in the process of scientific discovery through research [1-5]. Undergraduate research fosters investigative, communication and critical thinking skills, prepares students for postgraduate education and has been shown to increase student's interest in STEM careers [6].

We have developed a structured, rigorous, undergraduate research program through the School of Biological and Medical Sciences at the Rochester Institute of Technology (RIT) for students interested in pursuing independent and novel research experiences. Many undergraduate colleges and institutions offer students the opportunity to become involved in research, but unless elements of "**preparation, presentation, and publication**" are included in the program, there may only be weak association between undergraduate research and graduate school success [7]. Our Research Scholars Program (RSP) strives to bring those three elements into the research experience for undergraduate students enrolled in the program. This program also helps meet the four "Undergraduate Competencies", or skills that biology students should master during their undergraduate education to be scientifically literate, as reported by the National Science Foundation [8]. RSP could easily be modified or adapted to fit into any undergraduate college setting and can be easily expanded into other STEM disciplines.

2 RESEARCH SCHOLARS PROGRAM STRUCTURE

The Research Scholars Program has been in place at RIT since the Fall of 2004 and was designed for students who want to engage in serious undergraduate research for at least three quarters at RIT in

the School of Biological and Medical Sciences. The program provides students substantial hands-on experience designing and executing their own personal high-quality research projects under the guidance of their selected faculty mentor. Exceptional work accepted for publication in peer-reviewed journals will be published under the co-authorship of the student and faculty mentor. The vision of the program was to create an active community where students are encouraged to learn to think and talk science. In addition to providing invaluable experience designing, performing and presenting research the program includes many other benefits and activities. The basic elements of the program are summarized in **Figure 1** and described below.

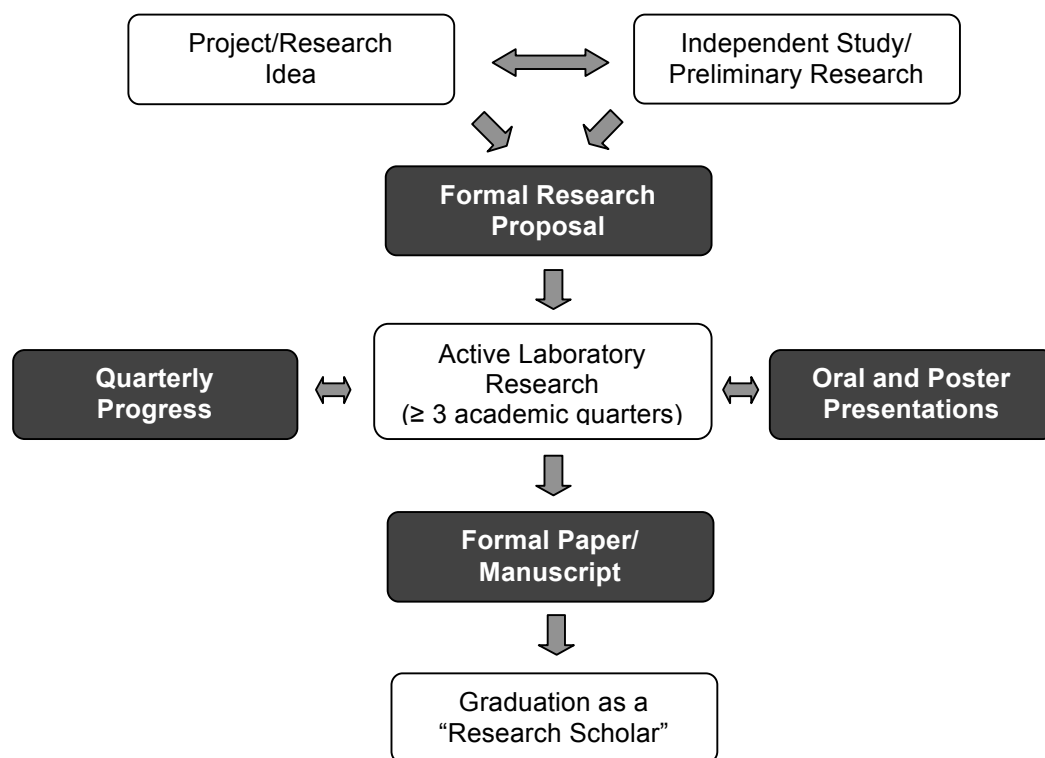


Figure 1. Steps to successful completion of the Research Scholars Program at RIT. While all aspects of the program require faculty mentoring and input, dark boxes denote areas requiring faculty review and feedback in the development of student communication skills

2.1 Project/Research Idea

Students who are interested in applying to RSP must first meet with a faculty member who has an active research program to establish interest and project feasibility. Research ideas are developed in accordance with the student's strengths and background. The projects are often extensions of projects that were begun by previous students, such that when results are linked together, they will generate a publishable paper. Some faculty members do allow their undergraduate research students to have greater control over the research idea and overall design of experiments, but this is rare given the pressures of producing publishable research.

2.2 Independent Study/Preliminary Research

At least one quarter of independent study or preliminary research (i.e. student review of the literature, inclusion in weekly laboratory meetings, inclusion in weekly journal club discussions, shadowing senior research students in the lab, hands-on training of basic laboratory techniques, and/or actually working on the research project) is recommended before a student is encouraged to apply for RSP. Thus, most RSP students will gain a pre-research experience or an actual research experience generating preliminary data that are invaluable for ensuring a successful student-faculty relationship. At RIT, both Independent Study and Biology Research are credit bearing courses (1-4 credits per quarter) and require 3-4 hours of student work per week per credit hour.

2.3 Application and Formal Proposal

To begin the formal application process, RSP students and their faculty research mentor write a research proposal which is open for review by any member of the RIT School of Biological and Medical Sciences Faculty and is actively reviewed by the RSP committee. The purpose of the review is to maintain the rigor of the proposed research projects. In addition to the research proposal, students must submit their transcript, a signed statement of support by their chosen faculty mentor, and a signed commitment to the program for at least three quarters. Students are required to have a minimum GPA of 3.0 to be eligible for RSP. This cutoff was chosen because students with a GPA below 3.0 are not usually competitive for admission to graduate school.

The RSP committee prepares a list of students who are recommended to the Department Head for acceptance into the Research Scholars Program. Accepted students are registered for Research Scholars I, which is a credit bearing course, for 1-4 credits (average 2). Again, 3 to 4 hours of student time working on the research project per week is expected per credit hour. To provide the greatest flexibility, students are not required to register for RSP courses in consecutive quarters, and they may receive credit for more than three quarters of research if desired. In order to register for RSP II and RSP III courses, they must submit quarterly progress reports, and receive a B or better in all RSP research courses.

2.4 Active Laboratory Research, Progress Reports and Presentations

Once accepted into the program, students engage in independent research for at least three quarters and submit quarterly reports detailing their quarterly research goals, progress, and future plans, and providing data in the form of figures for a paper. Progress reports are open for review by any member of the RIT School of Biological and Medical Sciences Faculty and are actively reviewed by the RSP committee.

RSP students are also required to give at least one formal oral presentation (approximately 20-30 minutes) during an RIT seminar series. Seminars given at RIT are open to all RIT students and faculty. During the second quarter in the program (the RSP II course), students must give an oral presentation at one of these forums. Students choose a panel of three faculty members (in addition to their mentor) to attend, evaluate and offer feedback on their research presentations. The grades assigned by the external evaluators for this presentation are incorporated into the student's grade for the course. A failure to give the presentation would result in a grade of C or lower and therefore expulsion from the program. In addition to the required oral presentation, the majority of RSP students also participate in poster sessions during RIT's Summer Undergraduate Research Symposium and/or present their work at a regional or national meeting. Traditionally they also organize a poster session each fall for the freshmen taking Introduction to Biology (our first year majors-level course).

2.5 Formal Paper/Manuscript

In order to complete the Research Scholars Program, students must write and submit a final paper that is in the format of a scientific journal article. These final papers are open for review by any member of the RIT School of Biological and Medical Sciences Faculty and are actively reviewed by the RSP committee at the completion of each academic year. The author of the best paper is awarded with the title of "Distinguished Scholar." In years where there was great difficulty in selecting a single "best" paper, joint prizes or "Honorable Mention" titles were also awarded.

2.6 Completion of RSP

Before graduation, each student completes a form showing that they have completed all of the requirements of RSP, including maintenance of GPA. Once approved by the Department Head, the students are recognized for their accomplishments. On the previous or same day as RIT Commencement, the students and their families are invited to the Research Scholars Award Ceremony. The Dean gives an opening address, and students are individually praised by their faculty research mentors and presented with a certificate of achievement and a medallion to wear at the Commencement ceremony. This is also where the Distinguished Scholar(s) is(are) announced. A reception follows the ceremony to celebrate the students' successes. At RIT Commencement, as the student crosses the stage, their name is followed with the designation of "Research Scholar".

3 RESEARCH SCHOLARS PROGRAM OUTCOMES

The Research Scholars Program at RIT is designed not only to enhance the undergraduate educational experience of students through novel research, but to foster collaboration and scientific communication skills of undergraduate students. Students participating in RSP are involved in research, laboratory meetings, and journal clubs and, therefore, must learn to balance their academic responsibilities and extracurricular obligations accordingly. The research and related activities through RSP help to improve students' abilities to meet the Undergraduate Competencies, which are newly defined by the NSF and enhance general learning outcomes. The program activities are highly regarded by the students, and are often praised by the faculty and administration.

3.1 RSP and the NSF Undergraduate Competencies

Our Research Scholars Program also helps to meet the four "Undergraduate Competencies," or skills that biology students should master during their undergraduate education to be scientifically literate, as suggested by the National Science Foundation [8]. Two of these goals (2 and 3) are specifically built into the program, while competencies 1 and 4 are outcomes of being involved in rigorous research projects at the level of an "investigator" rather than simply a "laboratory technician" (see Table 1).

3.2 Student learning outcomes

Information on student learning outcomes was collected using surveys based on Lopatto (2004). The results are summarized in Figure 2. Students were asked to rate their personal gain on potential outcomes of the program during their time in RSP on a scale of 1-5, with 1 being "none," 3 "moderate" and 5 "very large." Students who were currently enrolled in RSP (at any level) rated "Learning to work independently" as their greatest gain (4.3 ±1.2), followed by "Skill in how to give an oral presentation" (4.1 ±0.9) and "Tolerance for obstacles faced in the research process" (4.1 ±0.9). Note that the Graduates of the program also rated "Learning to work independently" as their greatest gain (4.5 ±0.8), along with "Understanding science in your field" (4.5 ±0.7). The smallest gain was seen in "Learning ethical conduct in your field" (3.0 ±1.4 and 3.2 ±0.3, respectively); however, this is not surprising since ethics was never purposely built into the program. In general the alumni saw greater gains, but this is also not surprising considering that they had all completed at least three quarters of research plus all the ancillary activities, whereas the "current students" surveyed had not.

Table 1. "Undergraduate Competencies" suggested by NSF and how RSP addresses them.

	Competencies	Addressed by RSP
1	<i>"understand the process of science, the interdisciplinary nature of the new biology and how science is closely integrated within society"</i>	<ul style="list-style-type: none"> Nearly all students participate in journal clubs or at least informal literature review and criticism with their mentors Many of the projects are interdisciplinary in nature, including collaborators from different fields. Many faculty within SBMS collaborate with each other, with experts from other departments at RIT (e.g. Chemistry, Statistics, Computer Science) and/or external scientists (e.g. University of Rochester, Rochester General Research Institute, Cornell University).
2	<i>"be competent in communication and collaboration"</i>	<ul style="list-style-type: none"> Students enrolled in RSP are required to give at least one formal oral presentation (20-30 minutes) at an RIT seminar series. Students in RSP are encouraged to participate in poster presentations at RIT Undergraduate Symposia and regional/national conferences specific to their disciplines. Students enrolled in RSP are required to write a formal research proposal, quarterly progress reports, and final paper in scientific journal-style format.
3	<i>"have quantitative competency and a basic ability to interpret data"</i>	<p>Students enrolled in RSP complete at least three quarters of independent research and must document, interpret, and present scientific findings in a variety of different formats:</p> <ul style="list-style-type: none"> one-on-one mentoring sessions with faculty laboratory meetings

		<ul style="list-style-type: none"> • oral presentations • poster presentations • progress reports • final paper
4	<i>“have some experience with modeling, simulation and computational and systems level approaches as well as with using large databases”</i>	<ul style="list-style-type: none"> • Students routinely use PubMed and similar searches for literature reviews, proposal and final paper writing. • Students are expected to develop research projects that could potentially be published in their field, thus familiarity with modern computational tools and/or systems level approaches are usually necessary. • Specific projects have included microarray analysis, mechanical engineering-driven cellular modeling, and genetic database design; others use sequence alignment tools (e.g. BLAST), gene network tools, SNP databases (e.g. dbSNP, HapMap), motif finders (e.g. ExPASy), and many other public database tools.

3.3 Students' plans after graduation

Surveys indicate that the majority of students enrolled in RSP were already considering graduate school when they began (**Figure 3**). As demonstrated by **Table 2**, every year at least half of all Research Scholars go on to attend graduate or medical school upon completion of their undergraduate degree, and the majority of those schools are classified among the 50 Top American Research Universities (as determined by The Center for Measuring University Performance [9]). Four recent graduates of RSP have won the prestigious, nationally competitive Barry M. Goldwater scholarship, which is awarded to juniors and seniors with “outstanding potential” who “intend to pursue careers in mathematics, the natural sciences, or engineering” (<http://www.act.org/goldwater/>).

Table 2. Success of Research Scholars

Year of Graduation	Total Research Scholars	Goldwater Scholars	Graduate/ Medical School	Top American Research University
2005	13		54%	71%
2006	5		60%	67%
2007	8		50%	100%
2008	10	1	70%	71%
2009	11	2	55%	83%
2010	9	1	56%	80%
Average	9.3		57%	79%

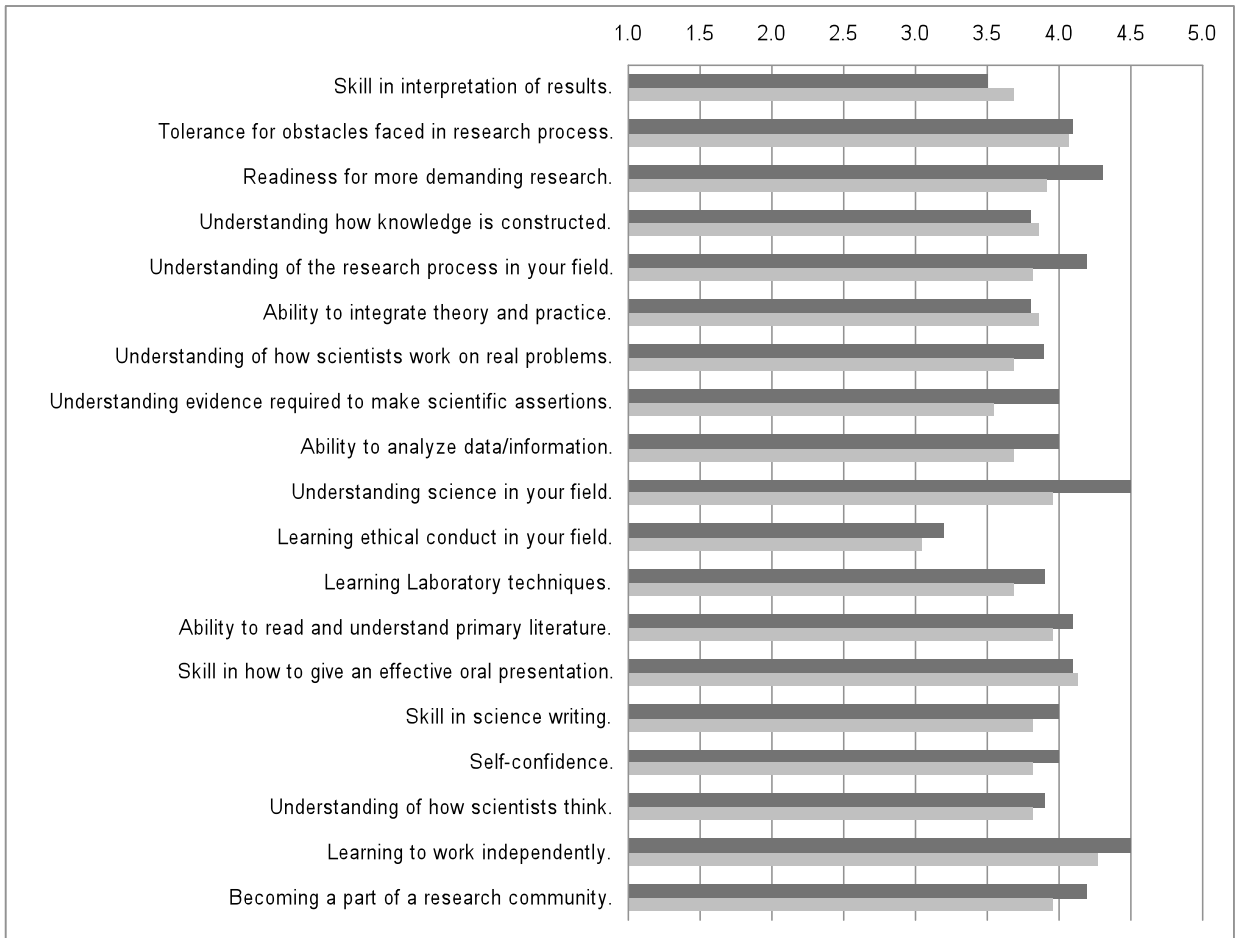


Figure 2. Student perceptions of skills gained through participation in the Research Scholars Program. Students were asked to rate their personal gain in each area during their time in RSP, where 1 = none, 2 = small, 3 = moderate, 4 = large and 5 = very large. Dark bars, survey scores from 10 RSP alumni (graduated in 2009 or 2010); light bars, survey scores from 22 students enrolled in the program (15 surveyed in 2008 and 7 surveyed in 2010)

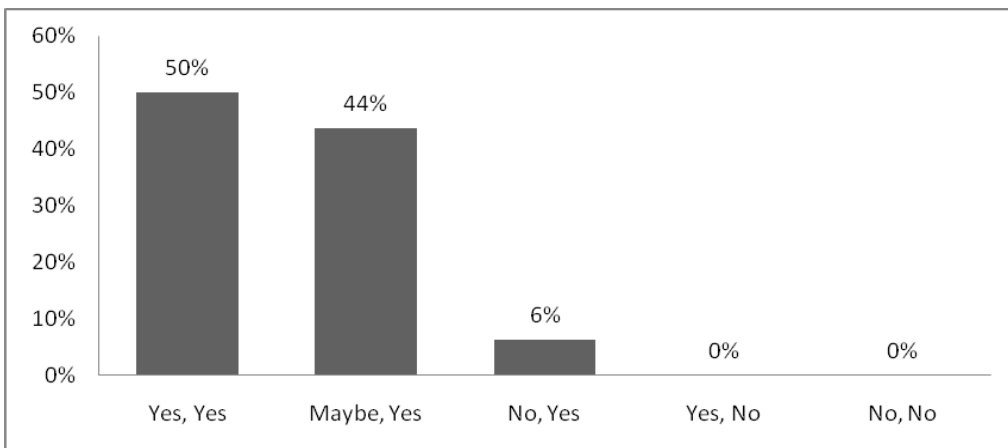


Figure 3. RSP student interest in graduate school. Students were asked whether they had planned to go to graduate school before entering the program (Yes, Maybe or No), and whether they were planning on pursuing a post-graduate degree after their experiences in the program (Yes or No). Data were collected from surveys of current students and recent program graduates (N=32)

3.4 Student perceptions about the program

Surveys given to the students show very positive perceptions about the program (**Figure 4**). Interestingly, students found the practice in communication skills to be most valuable. “Writing an initial research proposal”, “giving an oral presentation in the second quarter” and “writing a final paper in the form of a journal article” were the most highly rated components of the program. We were surprised and gratified to learn that our students appreciated being forced to practice these skills since we considered them critical elements of learning to be a scientist.

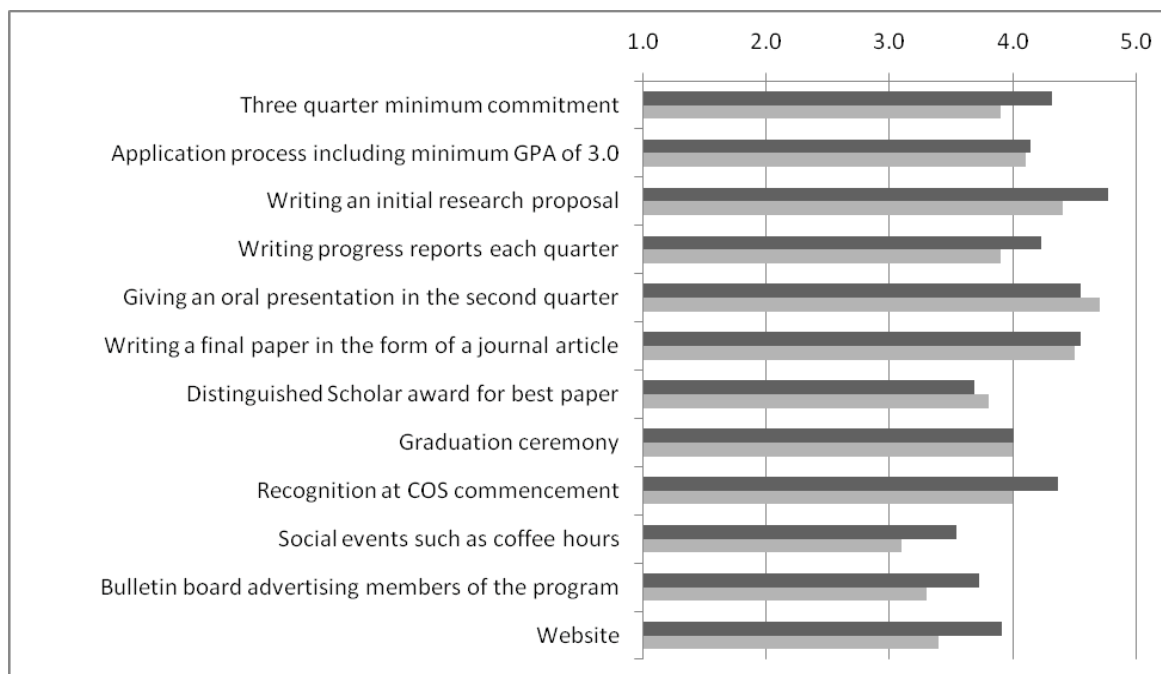


Figure 4. Student perceptions about elements of the program. Data were collected from surveys of current students and recent program graduates (N=32). Students were asked their opinions about components of the program, where 1 = waste of time/money, 2 = needs improvement to be worthwhile, 3 = neutral, 4 = worthwhile, 5 = essential to program. Dark bars, alumni; light bars, current students

Table 3. Student/mentor participation in RSP since its inception

	Total students	Total mentors	Students per mentor
Students who successfully completed RSP	56	14	4.0
Students currently enrolled	17	9	1.9
Students who did not complete RSP	10	5	2.0
Students ever involved in RSP	83	21	4.0

3.5 Faculty perceptions about RSP

Twenty-one faculty members have participated as a mentor for one or more RSP students in the past six years (**Table 3**). This number includes four new mentors whose students are currently enrolled but have not yet graduated. Currently our department consists of 30 full-time faculty in the Biological Sciences, six of whom do not have active research programs and several others who are new to RIT and still building their programs. Thus, the majority of faculty who could have acted as a mentor have done so at least once, and of those faculty, the average number of students is four (not necessarily concurrently; **Table 3**). Surveys given to faculty members demonstrate positive perceptions about the program (**Figure 5**). Those who have acted as research mentors tend to be most strongly supportive of the program, having experienced the benefits first-hand. However, it should be noted that the mentors probably also represent a subgroup who are biased toward valuing the skills emphasized in RSP. Both groups strongly supported the statements “RSP is beneficial to undergraduate students” (mean 4.0 and 4.6, respectively), “RSP helps prepare students for successful postgraduate education”

(mean 4.2 and 4.5), and “RSP is effective at teaching students to communicate/disseminate their research” (mean 4.0 and 4.5).

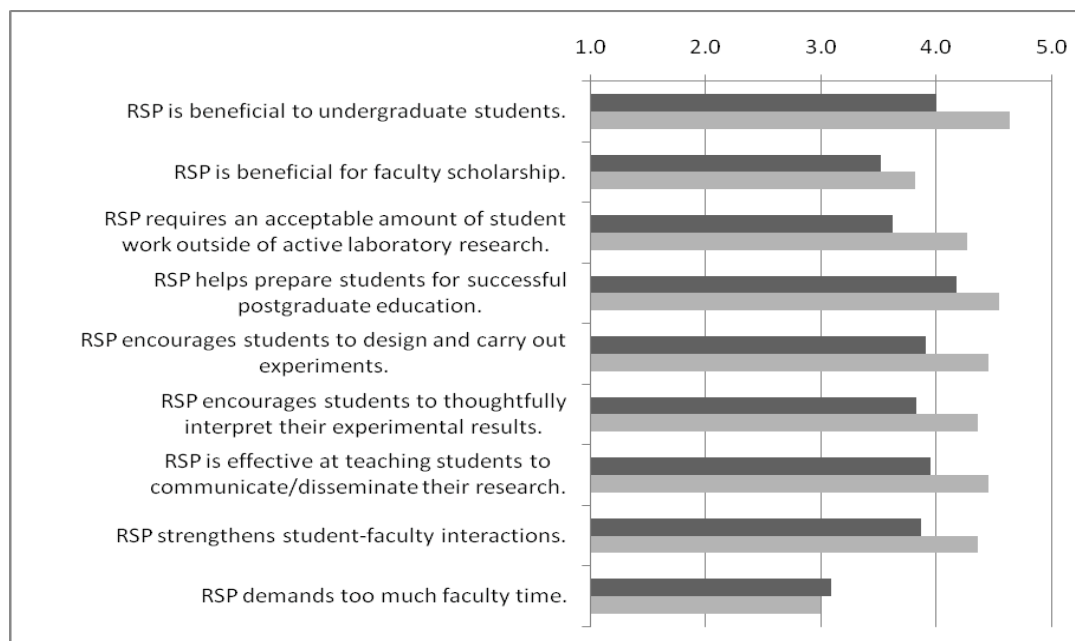


Figure 5. Faculty perceptions of the RSP. Current Faculty of the School of Medical and Biological Sciences were surveyed on their opinions of the program, where 1 = strongly disagree to 5 = strongly agree. Dark bars, all responses (N=26); light bars, only faculty who have acted as a mentor for one or more graduates of the program in the past 3 years (N=11)

4 RESEARCH SCHOLARS PROGRAM CHALLENGES

The Research Scholars Program has its fair share of challenges. Perhaps the most important challenges are faculty support for the program and students who do not make the grade.

4.1 Faculty Buy-in

As reviewed by Prince *et al.* [10], goals of research and teaching can be quite different (i.e. publication vs. effective teaching techniques) and often require faculty to have different sets of skills, resources, and expectations. In addition, teaching and research can each consume vast amounts of time, such that one often takes away from the other [11]. As would be found in many university or college settings, members of the faculty are a diverse group; some are more focused on service and teaching and do not have active research programs. Other members are involved in scholarship activities (i.e. pedagogical research) and curriculum development that afford fewer opportunities for undergraduate student involvement. Although most faculty have a very favorable perception of the program (**Figure 5**) and are willing to provide extra mentoring for the benefit of the student, not all faculty members are able or willing to commit fully to the program. In part, this is likely due to the high demands on faculty time for high quality teaching, advising, service and conducting publishable research. Assisting students during the application process, reviewing quarterly progress reports, poster and oral presentations can sometimes add up to too many demands for a faculty member.

4.2 Students who do not make the grade

In addition to the 56 successful graduates of RSP, we have had 10 students enroll in one or more RSP courses yet fail to complete the program (**Table 2**). Two of the students could not continue with the RSP sequence because of poor grades, one student tragically passed away before graduating, and seven lost interest or momentum regarding their research projects. It should be noted that five of those seven students who dropped out were enrolled in the very first year that RSP was offered, when details and policies of the program were still being reviewed and reworked. It is quite possible, then, that those students (or their mentors) did not know what they were getting into. For instance, three of the five were enrolled under a single mentor who never communicated with the RSP committee or participated again.

5 ADDITIONAL PROGRAM ITEMS

Several additional items can be added to the Research Scholars Program to enhance its appeal to both students and faculty, many of which would require additional funding. Surveys indicate that students found all of these “extras” to be worthwhile (data not shown).

5.1 Fellowships and Cash Awards

For several years the RSP at RIT was able to offer one student a paid summer fellowship (\$3,000) to continue their research project full-time during the summer quarter. RSP was also able to offer two \$500 travel awards for students wishing to present their work at a National Meeting of their discipline. RSP students who competed for these fellowships and/or travel awards were required to write additional proposals, which were reviewed and decided upon by the Research Scholars faculty. While these additions are certainly not required to run a rigorous and successful Research Scholars Program they were two wonderful ways in which we could support the enrolled students.

In the first few years of the program, we gave a cash prize of \$500 for the best paper; however, recently we have only awarded the title of Distinguished Scholar with no money attached. Although this was a nice reward for the winners, most students seemed unaware of the monetary incentive ahead of time. The primary incentive for writing a quality piece of work comes from the faculty mentors, who generally insist on their students submitting an article they would be comfortable submitting to their own peers for review.

5.2 Further Events and Activities

Each Fall students are welcomed into RSP with a small ceremony (which includes cake and other refreshments provided by the department). New and veteran RSP students as well as faculty mentors are invited. By organizing these simple events, the RSP committee hopes to reach out to students, show them that they are valued, and to encourage a sense of community among the group.

RSP has also experimented with other types of community building activities, ranging from coffee hours to outreach activities. For several years a summer journal club was held to discuss “hot topics” with summer research students, including many RSP members, which were well attended. In the past RSP students designed and ran a set of science activities for children who attended *Imagine RIT* (a festival for the public that showcases “Innovation and Creativity” by the RIT community). Several years of experience solidified the hypothesis that student-driven activities are better received and more successful than activities created around faculty’s perceptions of what students would enjoy. Electing student officers for the group can be a way of empowering them to organize these activities, and any financial support that the administration can provide is certainly helpful.

5.3 Faculty support

Students are usually very thankful for the experiences given to them through the Research Scholars Program and the administration is often very generous with praise for the faculty in their commitment toward training the next generation of scientists. At RIT, some resources exist in the form of competitive supply grants and summer salary grants. However, these resources are not universally available for all students who want to do research with faculty. This is not a problem for those linked to well-funded faculty members, but for those who do not have access to external or internal funds, further support for mentoring undergraduate research students is important for maintaining the enthusiasm of the faculty. Such support could be in the form of teaching release, summer salary, supply money and/or travel funds.

6 CONCLUSIONS

In conclusion, we present a structured research-intensive program for undergraduate students that helps fulfill NSF-directed scientific competencies and helps prepare students for success in graduate programs. Forty-four (79%) out of the 56 students who have successfully completed RSP have been accepted into post-graduate programs at Top American Research Universities. Students rated outcomes such as “Learning to work independently”, “Tolerance for obstacles faced in the research process” and “Understanding science in their field” very highly. “Preparing and giving oral presentations” and “Writing initial research proposals and final papers” were also considered valuable aspects of the program. Both current and RSP alumni demonstrated favorable perceptions of the

program. Participating faculty also voiced favorable opinions for this program claiming that RSP “strengthened student-faculty interactions” and greatly enhanced student abilities to “design and carry out experiments”, “interpret results” and “disseminate results.”

While RSP faces challenges such as faculty buy-in and financial support, the advantages to this program far outweigh any obstacles we have faced so far. While additional program or institutional support can enhance programs like RSP, design and implementation does not require it. The features of the program are not specific to RIT or Biological Sciences, so RSP could readily be modified or adapted to fit within many undergraduate settings and could easily be expanded into other STEM disciplines.

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