Development and Assessment of an Undergraduate Research Community

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Abstract

Literature suggests the benefits to undergraduate research include improving students' understanding of the research process, their resilience, and their ability to persist through failure. However, at primarily undergraduate institutions, there are a number of challenges in making the undergraduate research experience successful for both students and faculty mentors. First, there is a significant burden on faculty mentors who, along with designing a research project, are typically individually advising students, training them in reading and writing about research, and critiquing posters and presentations. These are skills which could be addressed more broadly among all research students. Additionally, due to limited opportunities for group interactions during summer research and the number of faculty advising individual students, students may lack a research community for interaction and support.

To develop a set of best practices for undergraduate research at our institution and support both student and faculty development, we initiated an Undergraduate Research Community (URC). For two summers, we offered workshops aimed at developing general research skills (reading and interpreting the literature, abstract writing, visualizing data, preparing posters, and applying to graduate school), along with social activities and opportunities for informal presentations.

This paper will discuss the structure of the URC at the authors' institution and related results from perception and direct assessment surveys. Before and after their research experiences, students completed a self-assessment regarding their competency in research skills and attitudes, and their feelings of involvement in the broader engineering community. To build upon previous work, which has primarily relied on self-assessment by students, faculty, and alumni, students answered open-ended questions from a previously published assessment of student knowledge of experimental design, and a group of faculty evaluated their answers according to a standard rubric. Finally, select students and faculty mentors were interviewed to better understand strengths and weaknesses of the URC.

Several positive outcomes emerged as a result of the URC. First, a large number of women underclassmen with one term or less of prior experience participated in summer research activities and in the URC in 2017 and 2018. Second, all students reported significant improvements in their abilities to engage in various research-related behaviors. Specifically, planning and designing experiments, using primary literature, and writing testable hypotheses were most significantly impacted when comparing pre- and post-survey data. Students also reported a significant increase in their confidence in designing experiments, performing research, and communicating findings. Perhaps most importantly, students noted that they felt part of the larger scientific and engineering community after their experience. Finally, over 75% plan to continue their research beyond the summer and pursue graduate school.

Introduction

Motivation

In 2018, record numbers of students applied to internal research funding for summer research programs at Rose-Hulman Institute of Technology. Due to the one-on-one mentoring and collaborative environment at Rose-Hulman, research experiences provide quality learning opportunities for students to improve critical thinking skills and prepare for future careers in research or industry. However, students may be the sole student working on a research project such that the work can be lonely, and faculty have the burden of training an undergraduate student – in many cases an underclassman – to perform research in a short, 10-week summer period. To address these needs, an Undergraduate Research Community (URC) was piloted summers of 2017 and 2018 to support research training and community-building for all undergraduates carrying out on-campus research during the summer.

A variety of undergraduate research (UR) programs have been evaluated at liberal arts and research-focused institutions. While undergraduate, engineering-focused institutions like Rose-Hulman are uniquely positioned to provide rich UR experiences, such programs, and the understanding of the extent of student impact, are limited. Understanding the impacts of UR could be especially valuable in disciplines such as environmental engineering, where degrees are more frequently awarded as specializations at the graduate level, and experiences outside the classroom may play a significant role in developing student interest. In 2016-2017, nearly 50% of all degrees under the titles "Environmental Engineering" or "Civil and Environmental Engineering" were awarded at the Master's or Ph.D. level, compared with 25% of all degrees titled "Mechanical Engineering" [1].

Our goals in this work were two-fold; first, we wanted to support students conducting UR on campus in the summer and provide them with formal opportunities for training through a structured URC. In the environmental engineering REU program at Clarkson, Grimberg et al. found that an interdisciplinary seminar program primarily focused on sustainability increased UR students' satisfaction with their summer experiences. This increase in satisfaction was attributed to reinforcing the larger context of students' research, and not the added peer interactions, since there were other opportunities for peer interactions [2]. This finding suggests value in interdisciplinary seminars for students' learning and motivation. In concert with the URC, we wanted to pilot several methods for assessment of the impact of UR on student learning, confidence, and career plans at our institution. These assessments included student perception surveys (self-assessment), student experimental design assessments, and student and faculty interviews. Moving forward, the assessment results and impressions of the initial URC can be used to evaluate the strengths and weaknesses of the UR program at Rose-Hulman and understand the value of the program for student learning relative to other on-campus activities.

Literature review

A growing number of students are seeking research opportunities at Rose-Hulman and literature suggests real benefits of UR. These benefits include improving their understanding of the research process and laboratory techniques, and their resilience and ability to persist through failure [3], [4]. Responses to NSF surveys of students participating in sponsored UR opportunities indicate that research experiences also helped increase student interest in STEM careers and in obtaining an advanced degree [5]. Interviews with undergraduates and faculty mentors at several liberal arts colleges suggest that UR also aided in the process of "becoming a scientist" – understanding the norms of professional practice and connecting to the field [6], [7]. Especially in terms of "developing an identity as a scientist", students cited the impact of UR more than coursework or the general college experience.

While many studies have focused on students in the sciences, especially biology, studies have also been conducted on the specific impact within the engineering curriculum. At the University of Delaware, Zydney et al. conducted a study of the impacts of UR through a survey of alumni of the College of Engineering [8]. Questions about outcomes of the college experience were distributed to alumni who participated in UR, as well as those who did not. The authors found that students who participated in the Undergraduate Research Program showed significant increases in their self-reported ability to speak effectively, understand scientific findings, and possess clear career goals. In a companion study with engineering and science faculty, Zydney et al. found that faculty believed that UR contributed to students' intellectual development, especially in terms of curiosity, ability to approach complex materials, and ability to understand scientific findings [9]. A study on a National Science Foundation funded Research Experience for Undergraduates (REU) program in environmental engineering at Clarkson University found that career goals were clarified as a result of the program [2]. Analysis of a cohort of undergraduate researchers at the New Jersey Institute of Technology, which emphasizes engineering as well as other STEM majors, showed that the students completing the UR experience had statistically significant increases in cumulative GPA and ratio of earned to attempted credit hours [10].

Although multiple studies have already illustrated various impacts of UR, more work is still needed in several areas. At Rose-Hulman, we are interested in how participating in undergraduate engineering research conducted in small groups or one-on-one with faculty members affects student learning and attitudes. Studies of UR in engineering disciplines mainly focus on R1 universities, where undergraduate researchers may be mentored by graduate students instead of directly by faculty members. In interviews of female students participating in an UR program in computing, interaction with graduate students was a key aspect, as many students spent more time working with graduate students than faculty mentors [11]. At smaller undergraduate institutions, most work has been conducted on impacts of UR in science and mathematics, which provides valuable insight in the overall experience at small universities, but may not address the differing project types and motivations of engineering students. For example, Reisel et al. note that in interviews with engineering students participating in UR at the University of Wisconsin-Milwaukee, students were interested in gaining applied skills, and did not necessarily come to college with the intention of doing research [12].

In addition to the need for institution- and discipline-specific information, there is also need for a broader range of methods to evaluate UR. In 2017, the National Academies of Science, Engineering, and Medicine issued a report titled "Undergraduate Research Experiences for STEM Students: Successes, Challenges, and Opportunities" [13]. A portion of the report summarized studies to date on the outcomes of UR experiences and cited future areas for research. Specifically, the authors noted that evidence of improvements in STEM disciplinary knowledge through UR is often based on student self-assessment. It would be valuable to couple student surveys with evaluation of artifacts designed to assess student skills in a specific area, such as experimental design or scientific writing. Additionally, Kardash et al. noted gender differences in students' self-reported improvement in research skills [14]. While mentor ratings of the students did not vary significantly by gender, in self-assessments, female students reported smaller increases in their abilities to understand concepts in the field and formulate research hypothesis.

Approach

The goal of the URC was to provide academic and social support for students and faculty during summer research activities. The URC consisted of a series of workshops and lunch gatherings to teach students research skills and to allow for interaction and collaboration. These were designed to reduce the faculty burden associated with teaching general research skills. Faculty lunch gatherings also allowed faculty to interface and share best practices. Initial assessment from the limited pilot summer of 2017 suggested that the workshops helped students develop critical skills to be successful researchers, allowed students the opportunity to explore research as a career option, and most importantly, allowed students to identify as part of the engineering research community. As a result, in 2018, workshop offerings were expanded (Table 1).

Table 1. Workshop offerings in 2018

Week	Workshop Topic
1	Opening symposium
1	Resources for searching literature
2	Organizing literature articles
4	Reading and interpreting primary literature
6	*Grad panel lunch*
7	Understanding imposter syndrome
7	Visualizing data
8	Writing Abstracts
9	Making Posters
10	Closing Symposium

Workshop presenters were experts in the workshop topic areas, and presented interactive, one-hour sessions. All workshops were presented by faculty or staff on campus with the exception of one workshop for which a post-doctoral researcher was brought to campus. The opening symposium welcomed students and allowed students to get to know their fellow summer researchers. Specifically, students were asked to reflect on M.A. Schwartz's essay, "The Importance of Stupidity in Scientific Research". As a result of this activity, most students committed to documenting a non-academic, "novice" experience during the summer. Students reported out on their novice experiences as well as presented lightning talks summarizing their summer research at the closing symposium.

To foster camaraderie among the students, students were encouraged to meet for lunch every Friday and were provided conversation prompts (Table 2). To allow students to discuss ideas and concerns freely, these gatherings were strictly for students. Similarly, faculty mentors met for lunch twice over the summer.

Table 2. Conversation prompts for student Friday lunch gatherings in 2018

Week	Conversation prompt
2	Did recognizing that we – the larger scientific community – don't have answers to many things empower you? How could you develop a support system to help you along as the way, as you approach new problems where the answer is not known?
3	What are you planning to do over the July 4th holiday?
5	What motivated you to pursue research over the summer? So far, is it what you expected? Why or why not?
6	*Grad panel lunch*
7	What challenges have you run into and how did you overcome them? What problem are you currently working to resolve?
8	How much time have you spent writing? Is it more than you thought you might? Thinking forward, does it need to be more? Less?
9	Reflecting back on the summer, what are some lessons learned that would have made your research experience more productive?

Implementation

In two consecutive summers, nearly 90 undergraduate students participated in research activities at Rose-Hulman. The URC cohort consisted of 43 students representing 15 majors in 2017, and 46 students representing 13 majors in 2018. The vast majority of students were majoring in an engineering discipline: 62% were majoring in engineering, 29% were majoring in science, and 9% were majoring in math (counting all majors, including double majors). Examples of projects relevant to environmental engineering in our study include characterization of a constructed, treatment wetland for removal of stormwater pollutants, removal of phosphate using limestone in a constructed treatment wetland, efficacy of a slow sand biofilter for turbidity and coliform removal, and development of an *Escherichia coli* strain to degrade polyethylene terephthalate in a biodigester setting.

Of students who responded to our survey (n=22), more than 50% had no prior research experience, an additional 26% had one term of experience and no students reported more than two terms of experience. It is possible that some students with more research experience were on campus, but did not respond to the survey questions. Notably, more underclassmen were involved in 2018 (Table 3). In 2017, the percentage of female participants (46.5%) was more than twice the percentage of female students enrolled at Rose-Hulman, and in 2018, an astounding half of the participants were female (Table 3). In both years, these students were mentored by 25 faculty members, of which a greater proportion were female than the Rose-Hulman average of 23.1% (Table 4).

Table 3. Student demographics

		2017 *N=43*	2018 *N=46*
	Males	53.5%	50.0%
	Females	47.7%	50.0%
Rising	Sophomores	27.9%	47.8%
	Juniors	34.9%	39.1%
	Seniors	37.2%	13.0%

Table 4. Faculty mentor demographics

	2017 *N=25*	2018 *N=25*
Males	71%	64%
Females	29%	36%
Assistant Professor	36%	52%
Associate Professor	28%	24%
Professor	36%	24%

Of the 46 students engaged in research in 2018, approximately 40 students participated in the Opening Symposium, and 20 students participated in the Organizing Literature Articles workshop. The most attended workshops were the Opening Symposium, Closing Symposium, and Visualizing Data workshop.

Assessment Methods

Along with developing the URC to provide training and community-building activities for undergraduate researchers, we also sought to understand the impact that the summer research experience had on student development. To evaluate students' progress in skills, interests, and attitudes associated with UR, we developed and administered pre and post surveys of student perceptions, post surveys of faculty mentor perceptions, and experimental design pre and post surveys for the students (Appendix I). We also solicited follow up interviews with a few students and faculty. The surveys and interviews were conducted by the Institutional Research and Program Assessment at Rose-Hulman, and following internal review board requirements, informed consent was obtained from each participant prior to participation.

Perception Surveys for Students

A number of surveys have been developed to assess changes in student attitudes and skills associated with UR and have been administered either immediately after research experiences [3], [14] or at a later time to program alumni [9], [15]. For this study, we drew from a set of previously published self-rating questions [14] to develop a survey, which would allow to us to analyze students' perceived value of their summer research experiences. Questions were selected that would apply across various engineering and science disciplines for 10-week research projects. Students were surveyed prior to their research experiences and again immediately after their summer research experience. In addition to the research skills questions drawn from [14], we asked about students' prior research experiences, time management, sense of confidence and belonging, dissemination plans, and participation in the URC. The full pre and post surveys can be found in Appendix I.

Experimental Design Surveys

As stated in a recent National Academies report on UR programs [13], there is a need for data to supplement student self-assessments of UR impact. As an alternative method to assess changes in students' abilities to perform skills related to research, students completed a questionnaire originally developed by the New York State Education Department, which is available from an online database, Performance Assessment Links in Science [16]. In this assessment, students were asked to develop a hypothesis, propose a basic experimental design, and state how experimental results would be interpreted in testing of a new high blood pressure drug. The questions from this assessment were previously used in development and validation of a rubric to assess student understanding of experimental design in undergraduate biology courses [17]. In this study, the assessment was used to provide additional insight into students' abilities in several areas where students were asked to provide self-assessments in the perception survey. The assessment scenario, questions, and proposed mapping to research skills from the perception survey are shown in Table 5, while the questions presented to students can be found in Appendix I.

Table 5. Experimental design scenario, assessment questions, and links to questions on perception survey.

<table>
<tr><th colspan="3">Scenario</th></tr>
<tr><td colspan="3">The drug ALAMAIN has been developed by the Gentronic Drug Company to lower blood pressure in people whose blood pressure is too high. The drug has been thoroughly tested on animals with positive results. The Gentronic Drug Company feels it is now time for the drug to be tested on humans, and have contacted the Human Improvement Laboratory (HIL) to do the testing.

Directions: As chief research scientist at the Human Improvement Laboratory (HIL) you have been assigned the task of developing the human testing program for the new high blood pressure drug Alamain. You and your assistants are to confer on the experimental design of this testing program, and to write a report outlining the program. The report is to be submitted to the chairperson of the HIL Drug Testing Committee for approval. Complete the following sections as you would include them on your report.</td></tr>
<tr><th></th><th>Experimental Design Assessment Question</th><th>Perception Survey Question</th></tr>
<tr><td>Q1</td><td>Using complete sentences, state the hypothesis to be tested.</td><td>Please rate yourself on your ability to write testable hypothesis.</td></tr>
<tr><td>Q2</td><td>Since there are several contributing factors that can affect blood pressure levels, list five factors that will be constant between the experimental and control groups.</td><td rowspan="4">Please rate yourself on your ability to plan and design experiments.

Please rate yourself on your ability to collect reproducible data.</td></tr>
<tr><td>Q3</td><td>Based on the factors you just listed, using complete sentences, explain why certain criteria need to be used in choosing the participants in this study.</td></tr>
<tr><td>Q4</td><td>Once the list of participants has been created, using complete sentences, explain how they will be selected to be a member of either the experimental or control group.</td></tr>
<tr><td>Q5</td><td>Using complete sentences, explain what measurements and/or tests will be made on the experimental and control groups to judge the efficiency of Alamain, and how often measurements or tests will be taken.</td></tr>
<tr><td>Q6</td><td>Using complete sentences, explain what criteria will be used to indicate the success or failure of the drug Alamain to reduce blood pressure levels in humans.</td><td>Please rate yourself on your ability to analyze or interpret data by relating results to your original hypothesis</td></tr>
</table>

Students' responses were assessed by faculty raters using a modified form of a previously developed rubric [17]. According to the rubric, a summary of which is shown in Table 6, students' responses were coded as "correct", "demonstrating an area of difficulty with experimental design", or "lacking evidence for assessment". Three faculty raters rated each response, and the majority rating was reported. Out of 252 coded responses, there were only two responses where no two raters agreed, and those responses were coded as lacking as evidence for assessment. In 63% of assessed responses, the coding of the response by all three faculty raters was identical.

Table 6. Rubric for coding student responses to experimental design questions

Difficulty	The response was coded as showing "difficulty" if it exhibited flawed understanding in one of five areas in experimental design identified in Dasgupta et al. [17]. 1. Variable property of an experimental subject 2. Manipulation of variables 3. Measurement of outcome 4. Accounting for variability 5. Scope of inference of finding
Correct	If the response did not exhibit a difficulty, it was coded as "correct" if it provided information consistent with correct response examples developed and published in [17].
Lack of evidence	If the response did not address the question or lacked sufficient detail to analyze for correctness versus difficulty with experimental design, it was coded as "lack of evidence".

Interviews with Students and Faculty

To investigate the impact of research and the URC on students' learning further, students and faculty mentors were solicited to participate in one-on-one interviews at the conclusion of summer research activities in 2018. Students were asked questions about their skills and confidence prior to and after their summer research experiences [14], and faculty were asked questions about how they observed their students skills and confidence change over the course of the summer [9]. Faculty were also asked to evaluate the value of the URC.

Results

Combining data from 2017 and 2018 allowed us to observe overall trends related to the impact of summer research experiences on students' skills, abilities to engage in research-related behaviors, and future plans. The data reported herein includes the responses of the 22 students who completed both the pre and post surveys. We observed trends in the mean values of responses, and identified statistical significance in some cases.

Pre and Post Perception Survey for Students

Students reported significant differences in their abilities to engage in various research-related behaviors as a result of their UR experiences (Table 7). All behaviors we inquired about were perceived as being positively impacted and we observed significant positive gains in six out of eight behaviors. Students specifically felt that they became better at planning and designing experiments, followed by writing testable hypotheses and using primary literature.

Table 7. Impact on students' abilities to engage in various research-related behaviors

Question: **Rate your ability to engage in various behaviors**. Responses options: 1=Poor, 2=Fair, 3=Good, 4=Very good, 5=Excellent	**Pre**		**Post**		*Sig.*	*Effect Size*
	M	*SD*	*M*	*SD*		
Plan and design experiments	3.35	0.67	4.00	0.97	***	0.8
Write testable hypotheses	3.40	0.88	4.00	0.79	**	0.7
Use primary scientific research literature (e.g., journal articles)	3.50	0.95	4.00	0.65	**	0.6
Analyze or interpret data by relating results to your original hypothesis	3.70	0.66	4.10	0.72	*	0.6
Collect data in a reproducible way	3.85	0.75	4.25	0.79	*	0.5
Redesign experiments to address new findings or challenges	3.65	0.75	4.10	0.91	*	0.5
Communicate findings (both verbally and written)	3.50	0.83	3.90	0.97		0.4
Manage time	3.70	1.08	3.85	0.93		0.2

Notes: N=20; ***p≤0.001, **p≤0.01, *p≤0.05; M is mean value, SD is standard deviation, Sig. is significant difference, and Effect Size is mean difference divided by the pooled standard deviation (0.2 (small), 0.5 (medium), 0.8 (large)).

While all behaviors were positively impacted as a result of their summer experiences, the students' rankings of their most impacted skills (Table 8) did not map to the statistically significant changes in behaviors identified (Table 7). For example, while more than half of respondents rated "communicate research findings" as one of the top three areas in which their summer research experiences helped improve their skills (Table 8), there was not a significant difference between students' pre and post survey results regarding their abilities to engage in communicating findings (Table 7). This could be because in Table 8, students were asked directly about the impacts of their experiences on development of various skills; this subtle difference in wording and the fact that it was only asked post-survey may have focused students' attention on certain activities.

Table 8. Skills selected as one of top three areas improved as a result of students' experiences

Question: **Select the top three areas in which your summer research experience helped you improve your skills**.	**Post-survey (N=22)**	
	N	*% Responses*
Communicate research findings (verbally or written)	12	55%
Engage in critical thinking and reflection	9	41%
Respond to challenges	9	41%
Use primary scientific research literature (e.g., journal articles)	9	41%
Design experiments	8	36%
Collect data in a reproducible way	7	32%
Approach problems creatively	4	18%
Analyze or interpret data by relating results to your original hypothesis	4	18%
Redesign experiments to address new findings or challenges	3	14%
Manage time	1	5%
Write testable hypotheses	0	0%

Additionally, students reported differences in their expected and actual time allocation for research-related activities (Table 9). On the post survey, students reported that they spent more time than expected on analyzing and interpreting data, using primary literature, collecting data or running code, identifying project constraints, redesigning experiments, communicating findings, and developing hypotheses. Students noted less time than expected on planning and designing experiments and looking for data. In addition, 36% of students reformulated their project goal or working hypothesis at least once, and 18% reported reformulating two, three, or four or more times. Overall, students' summer experiences were different than they may have expected, and as a result, they gained unanticipated skills and insights.

Table 9. Expected and actual time allocation

Question: **Indicate on which three activities you expect to spend / did spend the most time.**	**Pre**		**Post**	
	N	*%*	*N*	*%*
Collecting data in the laboratory or running simulations	9	41%	12	55%
Analyzing or interpreting data	7	32%	11	50%
Reading and interpreting primary scientific research literature (e.g., journal articles)	8	36%	10	45%
Communicating findings (verbally or through written reports)	9	41%	10	45%
Redesigning experiments to address new findings or challenges	6	27%	7	32%
Planning and designing experiments	10	45%	4	18%
Designing or building equipment	4	18%	4	18%
Identifying project constraints	2	9%	3	14%
Writing code	3	14%	3	14%
Developing testable hypotheses	1	5%	2	9%
Other	1	5%	0	0%

Note: N=22. On the pre-survey, students were asked to indicate on which activities they expected to spend the most time during their research project. On the post-survey, students were asked to indicate on which activities they actually spent the most time during their research project. On both surveys, students could choose three options. Other included: "Looking for data."

Students reported a significant increase in their confidence in designing experiments and performing research (Table 10), which aligns students' report in Table 7 that they improved their skills in planning and designing experiments. Next largest gains were made in students' confidence in applying skills from courses to projects outside class and feeling like part of the larger scientific and engineering community. Interestingly, students reported the weakest gains in feeling that they belonged to a scientific or engineering community on campus. Improving a sense of community was a goal of the URC, so this finding is unfortunate, but an opportunity to improve in future years. However, it is possible that this finding is not a result of a poorly executed URC, but a reflection of what Rose-Hulman already is: a small, STEM-focused college. No matter how many activities we plan over the summer, students will likely still feel less part of the scientific or engineering community in the summer than they do during their academic terms when all students are present and activities are in full-swing.

Table 10. Students' reported improvements in confidence, sense of belonging, and career goals

Question: **Indicate the degree to which you agree/disagree with the various statements**. Responses options: 1=Strongly disagree, 2=Disagree, 3=Neither Agree nor Disagree, 4=Agree, 5=Strongly Agree	Pre		Post		*Sig.*	*Effect Size*
	M	*SD*	*M*	*SD*		
I feel confident designing experiments and performing research	4.00	0.32	4.45	0.51	***	1.1
I feel confident applying skills from my courses to projects outside class	4.20	0.52	4.50	0.51		0.6
I feel like part of the larger scientific and engineering community	3.90	0.85	4.20	0.70		0.4
I have clear career goals	3.80	1.28	3.75	0.97		0.0
I feel like part of a scientific or engineering community on campus	4.50	0.51	4.45	0.76		-0.1

Notes: N=20; *Sig.* is significance in terms of ***p≤0.001, **p≤0.01, *p≤0.05; Effect size is the mean difference divided by the pooled standard deviation (0.2 (small), 0.5 (medium), 0.8 (large)).

At the conclusion of the summer, more than half of URC students stated that they planned to participate in dissemination activities by presenting their findings at Rose-Hulman, externally, and/or publishing them in an academic journal (Table 11). Additionally, more than three-fourths of URC students planned to continue their research beyond the summer and pursue graduate school (Table 11). This data in itself indicated to us that students viewed their summer experiences positively, or they would not be interested in applying to graduate school, even if they had self-selected into summer research due to their interest in graduate study.

Table 11. Self-reported publication and future research plans

Question: **Indicate if you plan to engage in these behaviors.** Responses options: yes or no	**Post-survey (N=22)**	
	N	*% Responses*
Continue your research beyond the summer	17	77%
Pursue graduate school	17	77%
Present your research findings at Rose-Hulman	16	73%
Present your research findings at an external conference	16	73%
Publish your research findings in an academic journal	11	50%
Publish your research findings as part of conference proceedings	5	23%

To gain insight into how students valued the URC workshops, students were asked to rank the workshops in terms of the three most beneficial to them. The two top-ranked workshops were Visualizing Data and Writing Abstracts. Related to the mechanics of the URC, some students also reported that it was helpful to have a classroom to work in for the summer. The Friday lunch gatherings were not well attended, and anecdotally we understand it is because there was not enough structure to the gatherings.

Post Perception Survey for Faculty Mentors

While faculty themselves did not attend URC workshops en masse (attendance varied between one and eight faculty), they saw overall value in the workshops. Faculty rated the value of the workshops at 4.6±0.5 out of 5 (Likert scale 1-5, N=12) and 4.8±0.5 out of 5 faculty mentors reported that they encouraged their students to participate. In describing their numerical answers, faculty stated that the workshop topics were relevant and that the URC allowed student engagement and camaraderie resulting in an overall positive experience. Out of the expected positive outcomes of the URC, faculty mentors reported students' communication abilities, confidence and curiosity were most positively impacted. Additionally, other key aspects of performing research including using primary scientific literature, designing experiments, and being part of the larger scientific community were also identified as positively influenced as a result of students' research experiences (Table 12).

Table 12. Faculty mentor ratings of students' development

Question: **To what extent did students' research experiences contribute to their intellectual and personal development in the following areas?** Responses options: 5=Very much, 4=Quite a bit, 3=Some, 2=Very little, 1=Not at all	**Post-survey (N=12)**	
	Avg	*SD*
Communicating findings (both verbally and written)	4.3	0.9
Developing confidence in designing experiments and performing research	4.0	0.9
Developing intellectual curiosity	3.9	0.7
Using primary scientific research literature	3.8	1.0
Planning and designing experiments	3.8	1.5
Gaining exposure to the larger scientific and engineering research community	3.8	0.8
Collecting data in a reproducible way	3.7	1.3
Analyzing or interpreting data by relating results to original hypotheses	3.7	1.2
Redesigning experiments to address new findings or challenges	3.5	1.4
Having clear career goals	3.4	0.8
Managing time	3.3	1.0
Writing testable hypotheses	2.9	1.3

Of the faculty who attended the monthly faculty lunches, 3.9±0.7 (Likert scale 1-5, N=7) valued the faculty lunch gatherings for sharing mentoring tips. Most discussions revolved around common mentoring challenges across disciplines and ideas for overcoming them, as well as future funding options. One faculty mentor suggested that they may have been more enthusiastic about attending if the gatherings were regular weekly meetings and another person wished that the gatherings had more structure to them.

Pre- and Post-Experimental Design Survey

In 2017 and 2018, a total of 21 students responded to the experimental design assessment questions on both the pre and post surveys. Most student responses could be coded by faculty members as correct or exhibiting difficulty in an area of experimental design, with a relatively small number of responses lacking evidence for evaluation. On the pre survey (Figure 1), the majority of undergraduate researchers already responded correctly to questions requiring generation of a testable hypothesis (Q1) and design of an experiment (Q2-Q5). Students showed more instances of difficulty in stating criteria for analyzing the outcome of the drug trial (Q6). To correctly answer this question, students would need to have a strategy to relate their results to their original hypothesis.

On the post survey, although there was a significant gain in students' self-assessment of their ability to formulate a testable hypothesis (Table 7), no improvement was demonstrated in their ability to correctly state a hypothesis in this assessment (Figures 1 & 2, Q1). In fact, fewer student responses on the post survey were coded as correct than on the pre survey. The total number of correct responses to the experimental planning questions (Q2-Q5) was nearly constant between the pre and post surveys. Students did self-report increased abilities to plan and design experiments (Table 7), but given the large number of correct responses to these questions on the pre survey, student gains may be at a higher level than what is required in this assessment. Finally, Q6 of the experimental design assessment most closely maps to the perception survey question regarding students' ability to analyze or interpret data by relating results to a hypothesis. In this case, an increase in the number of correct responses was observed on the post survey (Figure 2, 48% correct post vs 38% correct pre), although the result is not statistically significant (Fisher's exact test, $p = 0.31$).

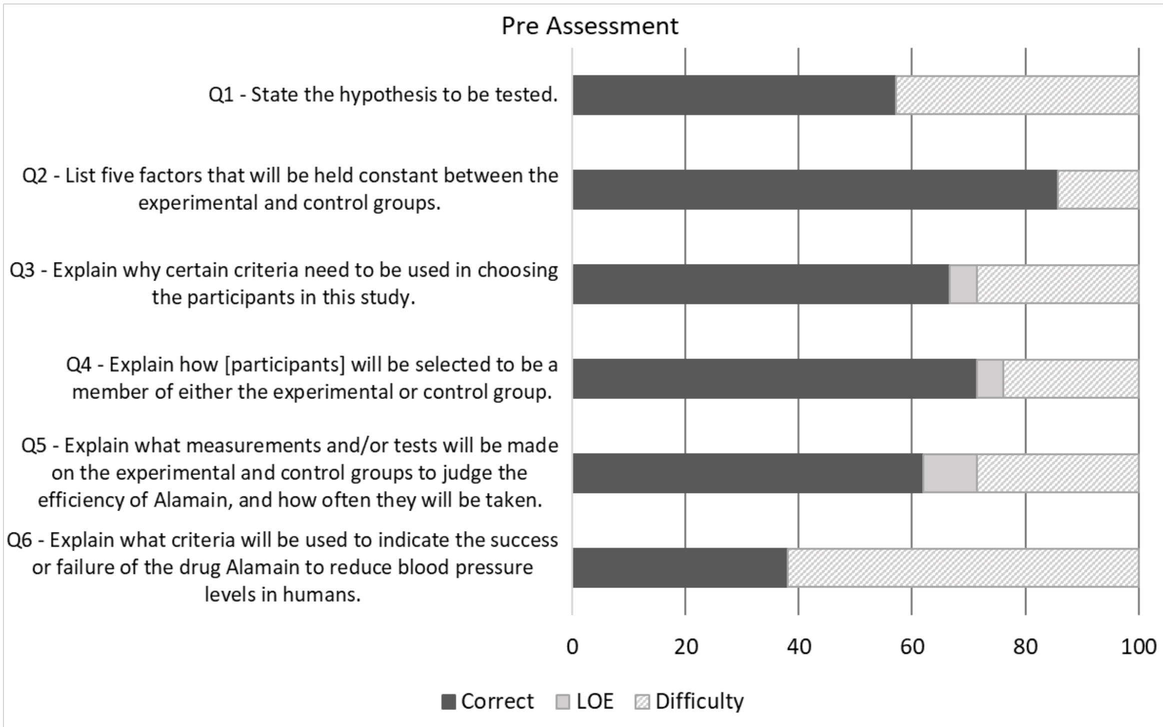

Figure 1. Percentage of students (n = 21) whose pre-survey responses to experimental design assessment questions were correct (dark grey), showed difficulty in experimental design (hatched), or showed a lack of evidence for assessment (light grey).

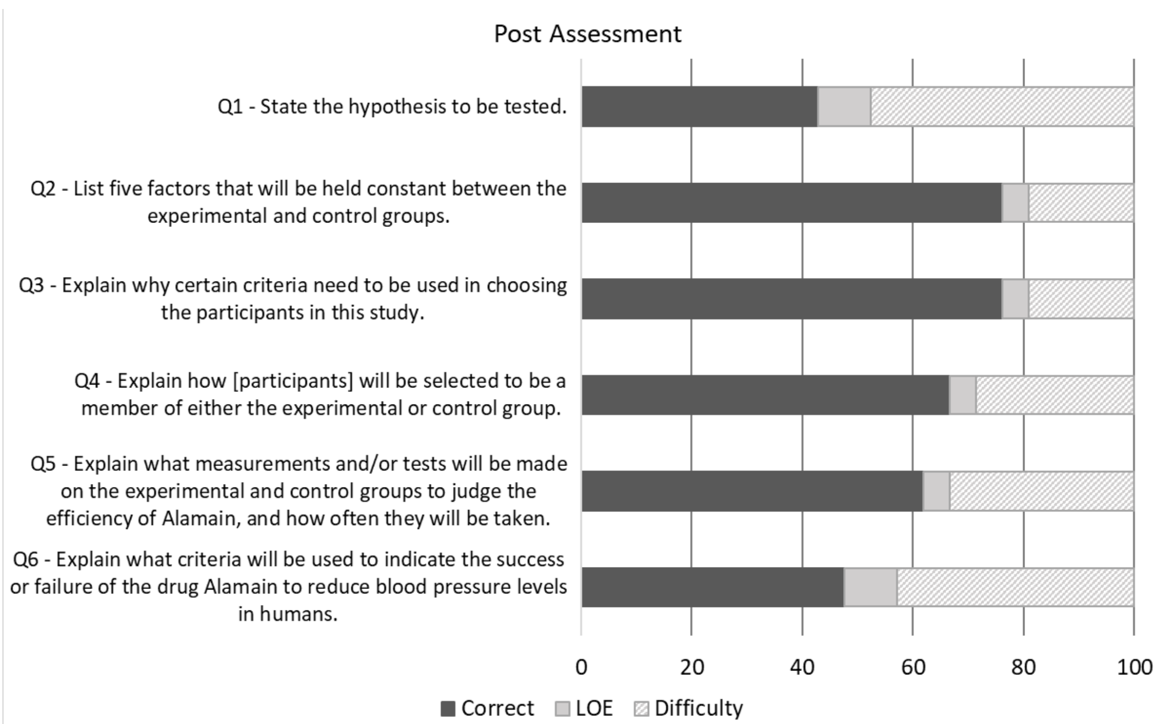

Figure 2. Percentage of students (n = 21) whose post-survey responses to experimental design assessment questions were correct (dark grey), showed difficulty in experimental design (hatched), or showed a lack of evidence for assessment (light grey).

Interviews
While a small sample, five students were interviewed and reported acquiring some common skills as a result of their research experiences. Most students described their research as open-ended, at least compared to classwork or previous research experience for undergraduates (REU) program experiences. Because of this, multiple students reported gains in their abilities to solve problems independently. Some students reported both a distaste for the frustrations that come with iterating hypotheses, experiments, prototypes and writing, as well as a sense of accomplishment from successful experiments or acceptance of an abstract or paper. Overall, students reported largest gains in their scientific communication skills, including writing scientific papers and presenting data. To improve the URC, students suggested including more opportunities for informal interactions. One student noted that he or she made friends in other departments through the URC and hung out with them in academic buildings when not stuck in the lab. This student acknowledged that it is hard to interact when stuck in the lab all day. However, this person suggested offering tours of each other's projects or lab areas so that students would know where others are located and could also see other projects in action.

Three faculty interviews were also conducted. Although this is also a limited sample, some themes emerged in faculty interviews that suggest additional areas for investigation. In evaluating student gains from the summer research experience, intellectual curiosity and openness to new ideas were mentioned multiple times. Faculty members saw increases in students' willingness to contribute their own ideas to projects and take ownership of their projects. Faculty comments indicated that there are still many areas for improvement in terms of community-building during the summer research experience. Student work habits varied, and faculty members mentioned that student interest in attending the less structured social activities, like brown-bag lunches, was low. Structured workshops around broadly-applicable themes like scientific communication or research ethics were viewed as most valuable.

Discussion

Although students did not report a significantly increased sense of belonging to the scientific / engineering community or greater clarity of career goals, they did report interest in continuing research and going to graduate school, which is indicative of engagement in the field. Because of the relatively small group of students, and the undergraduate focus of Rose-Hulman, students performing summer UR were still generally working independently or with a small group. This setup differs from large, research-focused universities, and was one of the main drivers for us to develop a URC at Rose-Hulman and allow for learning and fellowship across the university in the first place. This finding indicates that students are not being turned away from pursuing graduate school, and that perhaps even more students would be interested in pursuing graduate school or gain clarity of their career goals if the URC were modified to foster more community.

The results of the survey also indicate there is value in utilizing different types of questions and assessment methods to understand the impact of UR. Based on student ratings of their ability to communicate results (Table 7), it would appear that they did not make significant gains between the pre and post survey. However, when students are asked to rank their top areas of improvement, communication is clearly very important (Table 8). Even as their skills improve, students' self-assessment in a certain area may fall as they become exposed to more material and recognize previously unknown gaps in their knowledge.

The experimental design assessment also shows promise as a tool to supplement self-assessment by students and overall impressions of faculty mentors. In this case, students' self-reported gains in research skills (Table 7) did not show up in the experimental design assessment. However, the results were more consistent with faculty rankings, where "ability to formulate a testable hypothesis" was ranked lowest among areas impacted by the students' summer research experience (Table 12). Additionally, students themselves did not identify this skill as a top-three area of improvement over the summer (Table 8). Previous work has indicated that, compared to mentors, students tend to overestimate their abilities to understand the importance of controls and relate their results to the broader field [14].

We did see an increased number of correct responses on the post survey to a data analysis question (Q6). Although the result was not statistically significant, with a larger sample size, it might be possible to use an analysis such as this to support student-reported improvements in this area of interpreting and analyzing data (Table 7). However, it is also likely that some discrepancies between the experimental design assessment and student-reported gains can be attributed to weaknesses in the administration of this particular assessment. The same assessment was given on both the pre and post surveys and student memory of the questions may influence their post-survey answers. Additionally, the assessment was oriented toward the biological sciences and may not be as effective for assessment of engineering research skills, where the design-build-test cycle plays a more significant role compared with randomized trials. For future work, it would be valuable to develop additional assessments oriented toward engineering research skills, as well as to develop multiple scenarios, avoiding repetition of questions in the pre and post survey. These additional experimental design assessments could provide interesting information to supplement faculty impressions and student self-assessment.

Conclusions

Based on our findings, summer research activities allowed students to develop critical skills that will help them be successful researchers and explore research as a career option. Specifically, communication and data presentation skills were important and noted as improved as a result of UR experiences by both faculty and students. Communication and data presentation were also popular workshop topics. Additionally, based on pre and post perception surveys, students felt more confident in planning and conducting research after their summer experiences. Finally, based on students' self-reported improvements and direct assessment, students were better able to interpret and analyze data after completing their summer UR experiences.

Reflection and Future Considerations

Reflecting on two summers of executing the URC, we encountered a significant need for faculty mentor buy-in. In the future, we would ask – or require if their students receive internal funding – that faculty mentors expect their students to attend, and model attendance themselves. For internally funded students, we recommend that their funding be tied to completion of pre and post surveys, interviews, and participation in 75% of the workshops. For faculty members considering developing a URC, we suggest they acquire administrative support, as scheduling and executing the URC is nontrivial.

The results of this study suggest a number of areas for future work. Differences between student self-assessments, their rankings of skills gained in UR, and their performance on an experimental design assessment illustrate the need for a variety of assessment tools in understanding UR. Communication skills were a broad theme in faculty and student responses, indicating that an outside assessment of writing samples, such as a project abstract written from a prompt, may provide interesting insights. Additionally, we are interested in creating an experimental design assessment tool that would match better with typical questions in engineering design and research projects.

Our results thus far on the theme of community-building during UR are mixed. Although students did not indicate that they felt more integrated with the scientific/engineering community on campus after a summer research experience, their interest in graduate study remained high. Additional interviews or open ended questions may be valuable to allow broader themes to emerge in this area, which could serve as a basis for improving the UR experience and defining best practices. In a next iteration, we would aspire to having more structured informal opportunities for students to get to know one another, such as tours of project spaces, and lunch gatherings with mentors or student discussion leaders.

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Appendix I – Student and faculty surveys

Student pre survey (perception and experimental design surveys)

1. Please rate yourself on your ability to…
   (Response options: 5=Excellent, 4=Very Good, 3=Good, 2=Fair, 1=Poor)
   a. Use primary scientific research literature (e.g., journal articles)
   b. Write testable hypotheses
   c. Plan and Design experiments
   d. Collect data in a reproducible way
   e. Analyze or interpret data by relating results to your original hypothesis
   f. Redesign experiments to address new findings or challenges
   g. Communicate findings (both verbally and written)
   h. Manage time

2. How many terms (quarters) have you been involved in research? *(Response options: 0, 1, 2, 3, 4 or more)*

3. To what extent do you agree/disagree with the following statements.
   (Response options: 5=Strongly Agree, 4=Agree, 3=Neither Agree nor Disagree, 2=Disagree, 1=Strongly Disagree)
   - I feel confident applying skills from my courses to projects outside class
   - I feel confident designing experiments and performing research
   - I feel like part of a scientific and engineering community on campus
   - I feel like part of the larger scientific and engineering community
   - I have clear career goals

4. On which activities do you expect to spend the most time during your research project? Choose three options.
   - Reading and interpreting primary scientific research literature (e.g., journal articles)
   - Developing testable hypotheses
   - Identifying project constraints
   - Planning and designing experiments
   - Designing or building equipment
   - Writing code
   - Collecting data in the laboratory or running simulations
   - Analyzing or interpreting data
   - Redesigning experiments to address new findings or challenges
   - Communicating findings (verbally or through written reports)
   - Other

   Please specify if you selected Other to the previous question: (freeform)

5. The drug ALAMAIN has been developed by the Gentronic Drug Company to lower blood pressure in people whose blood pressure is too high. The drug has been thoroughly

tested on animals with positive results. The Gentronic Drug Company feels it is now time for the drug to be tested on humans, and have contacted the Human Improvement Laboratory (HIL) to do the testing.

Directions: As chief research scientist at the Human Improvement Laboratory (HIL) you have been assigned the task of developing the human testing program for the new high blood pressure drug Alamain. You and your assistants are to confer on the experimental design of this testing program, and to write a report outlining the program. The report is to be submitted to the chairperson of the HIL DrugTesting Committee for approval. Complete the following sections as you would include them on your report.

- Using complete sentences, state the hypothesis to be tested. (freeform)
- Since there are several contributing factors that affect blood pressure levels, list five factors that will be constant between the experimental and control groups. (freeform)
- Based on the factors you just listed, using complete sentences, explain why certain criteria need to be used in choosing the participants in this study. (freeform)
- Once the list of participants has been created, using complete sentences, explain how they will be selected to be a member of either the experimental or control group. (freeform)
- Using complete sentences, explain what measurements and/or tests will be made on the experimental and control groups to judge the efficiency of Alamain, and how often measurements or tests will be taken. (freeform)
- Using complete sentences, explain what criteria will be used to indicate the success or failure of the drug Alamain to reduce blood pressure levels in humans. (freeform)

Student post survey

The post survey included the questions in the pre survey plus the following additional questions.

1. Which workshops did you attend (check all that apply)?

   Opening symposium (6/15)

   Resources for searching literature (6/15)

   Organizing literature articles (6/18)

   Reading and interpreting literature (6/28)

   Applying to graduate school (faculty panel, 7/13)

   Understanding imposter syndrome (7/17)

Visualizing data (7/18)

Writing abstracts (7/23)

Making posters (7/31)

Closing ice cream social (8/10)

2. Of the workshops you attended, rank which three were most beneficial / provided the most value to you (1 = most useful).

   Opening symposium (6/15)

   Resources for searching literature (6/15)

   Organizing literature articles (6/18)

   Reading and interpreting literature (6/28)

   Applying to graduate school (faculty panel, 7/13)

   Understanding imposter syndrome (7/17)

   Visualizing data (7/18)

   Writing abstracts (7/23)

   Making posters (7/31)

   Closing ice cream social (8/10)

   Why did you choose these three?

3. I valued the Friday lunch gatherings (1=Strongly Disagree, 3=Neither Agree Nor Disagree, 5=Strongly Agree, N/A=Not Applicable).

   1 2 3 4 5 N/A

4. I thought it was helpful to have a classroom to work in for the summer (1=Strongly Disagree, 3=Neither Agree Nor Disagree, 5=Strongly Agree, N/A=Not Applicable).

   1 2 3 4 5 N/A

Faculty post survey

5. Which workshops did you attend, if any (check all that apply)?

   Opening symposium (6/15)

Resources for searching literature (6/15)

Organizing literature articles (6/18)

Reading and interpreting literature (6/28)

Applying to graduate school (faculty panel, 7/13)

Understanding imposter syndrome (7/17)

Visualizing data (7/18)

Writing abstracts (7/23)

Making posters (7/31)

Closing ice cream social (8/10)

6. I saw value in the summer workshops for my students (1=Strongly Disagree, 3=Neither Agree Nor Disagree, 5=Strongly Agree).

   1 2 3 4 5

   Why or why not? (freeform)

7. I think my students built friendships that were helpful to them this summer (1=Strongly Disagree, 3=Neither Agree Nor Disagree, 5=Strongly Agree).

   1 2 3 4 5

8. I thought it was helpful for my students to have a classroom to work in for the summer (1=Strongly Disagree, 3=Neither Agree Nor Disagree, 5=Strongly Agree, N/A=Not Applicable).

   1 2 3 4 5 N/A

9. I encouraged my students to participate in the undergraduate research community activities this summer (1=Strongly Disagree, 3=Neither Agree Nor Disagree, 5=Strongly Agree).

   1 2 3 4 5

   Why or why not? (freeform)

10. I valued the faculty lunch gatherings to share tips for mentoring students (1=Strongly Disagree, 3=Neither Agree Nor Disagree, 5=Strongly Agree).

1 2 3 4 5

Why or why not? (freeform)

11. How important do you think students' research experiences were to their intellectual and personal development in the following areas (1=Strongly Disagree, 3=Neither Agree Nor Disagree, 5=Strongly Agree):

a.	Developing intellectual curiosity	1	2	3	4	5
b.	Using primary scientific research literature	1	2	3	4	5
c.	Writing testable hypotheses	1	2	3	4	5
d.	Planning and designing experiments	1	2	3	4	5
e.	Collecting data in a reproducible way	1	2	3	4	5
f.	Analyzing or interpreting data by relating results to original hypotheses	1	2	3	4	5
g.	Redesigning experiments to address new findings or challenges	1	2	3	4	5
h.	Communicating findings (both verbally and written)	1	2	3	4	5
i.	Managing time	1	2	3	4	5
j.	Developing confidence in designing experiments and performing research	1	2	3	4	5
k.	Having clear career goals	1	2	3	4	5
l.	Gaining exposure to the larger scientific and engineering research community	1	2	3	4	5

12. I would be willing to participate in a brief, follow-up interview about these topics (freeform).