The Influence of Materials Science and Engineering Undergraduate Research Experiences on Public Communication Skills

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Abstract

Communicating research findings with others is a skill essential to the success of future STEM professionals. However, little is known about how this skill can be nurtured through participating in undergraduate research. The purpose of this study is to quantify undergraduate participation in research in a materials science and engineering laboratory, and relate this information to undergraduates' public communication skills. Descriptive information from an undergraduate survey response on the distribution of the quality of these research experiences across 10 weeks for eight undergraduate students is provided. This information is correlated with undergraduates' ability to publicly communicate their work with a wide audience during presentations at a local museum. Findings indicate that there is a variation between undergraduates in terms of the types of research activities that they participate in, how closely they work with graduate students, and how often they are asked to share their ideas and think about research activities. There is a positive and significant correlation between active participation in particular types of research activities and the ability to communicate their work with a wide audience.

Keywords: undergraduate research, communication, engineering

There is great importance in supporting future STEM professionals to develop their communication skills. STEM professionals often work in interdisciplinary teams or groups, which create situations that require effective communication (Kalonji, 2005). In addition, STEM professionals are increasingly called upon to communicate information with a diverse audience as a way of increasing public awareness and engagement with critical STEM issues (AAAS, 2011). There are formal and informal ways that future STEM professionals develop verbal communication skills. In addition to enrolling in formal coursework, a less formal opportunity with potential to improve communication skills is for undergraduates to participate in research with a faculty member and graduate students (Cox & Andriot, 2009). The benefits of participating in undergraduate research has been widely studied (Zydney, Bennett, Shahid, & Bauer, 2002). Undergraduates participating in research can better prepare themselves for careers in engineering by acquiring content knowledge and technical skills, such as performing various laboratory procedures using different instrumentation, developing independent thinking, and improving communication skills and self-confidence (Seymour, Hunter, Laursen, & Deantoni, 2004). However, simply participating in research is not necessarily beneficial to students.

Researchers have called for attention to the quality of these undergraduate research experiences in relation to particular desired student outcomes (Sadler, Burgin, McKinney, & Ponjuan, 2010). The assumption is that it is not only important for students to participate in research, but it is also important to consider what students do when participating in research and how this participation relates to their ability to communicate their research to a broad audience.

There are several limitations to previous studies on undergraduate research that raise questions about the influence of undergraduate research experiences on communication skills. First, many undergraduates who participate in research tend to have high academic achievement and are highly motivated, thus, leading to a self-selection bias. Many of these students may already be effective at communicating compared to other students. Participating in research may have little to do with whether they are effective communicators. A second limitation of previous studies is the lack of information about the particular research experiences in which students engage. Without this sort of specific information, it is difficult to make recommendations to improve undergraduate research experiences. Finally, prior research has not been able to link specific research experiences to effective communication.

We address two of these limitations and contribute to the large body of literature on mechanisms to increase the quality of undergraduate engineering student experiences. Assuming that both the exposure to, and the quality of, these research experiences are significant contributors to effective communication, this study addresses the following research questions:

1. What is the structure and intensity of the undergraduates' research experience?
2. How does the structure and intensity of the undergraduates' research experience vary between students?
3. How does the structure and intensity of the undergraduate research experience relate to the undergraduates' ability to communicate their research to a broad audience?

In addressing these questions, this study provides information about ways of measuring undergraduate research experiences and relating these experiences to an outcome that is critical to the success of future engineers. This research helps to better understand which of the undergraduate working conditions, in terms of the structure and intensity of their research environments, are most productive to developing effective communication skills.

Method

Sample

The sample for this study was selected based on a pilot study conducted during the summer of 2010. During this pilot study, undergraduates were shadowed for one hour on two separate occasions, were individually interviewed on two occasions, and completed weekly surveys to document their participation in research. These undergraduates were mostly seniors, but represented a range of majors (Biological, Chemical, Computer Science, Electrical, Environmental, and Materials Science). These undergraduates worked with 14 faculty members and participated in a wide range of activities. There was substantial variation in student engagement between laboratories. For example, those who performed theoretical research typically sat in cubicles and wrote specific codes to develop models to describe specific phenomena. Conversely, students performing experimental research were in a laboratory environment, often surrounded by other undergraduate and graduate students who were working in teams to either synthesize or characterize new materials/structures. Given this overwhelming diversity of the research activities during the pilot study, it was decided that a single laboratory would be the focus of this particular study. Focusing on one laboratory enabled a more in-depth analysis of the workings of a particular research lab. It allowed the research staff to collect data throughout the quarter rather than at one or two time points. This particular laboratory was purposefully sampled because there was sufficient variation within the group that could be explored. The group is one of the larger research groups on campus that conducts research in at least five science and engineering fields (Chemistry, Chemical Engineering, Materials Science, Mechanical Engineering, and Molecular Biology). The primary focus of this research group is the development of biologically inspired, solution-based nanomaterial synthesis routes for use in energy and structural applications. Thus, despite the variety of approaches, there was a common focus that created a setting that could address the research questions posed for this study.

Undergraduates from this laboratory were recruited for participation in this study at the beginning of the winter 2011 quarter either through email or through personal interactions during a weekly research meeting. Students were informed that their participation would provide information on improving the quality of undergraduate research experiences, but they would not be compensated financially. Their participation was completely voluntary and a lack of participation would not compromise their standing in the research group.

The final sample included for this study consisted of eight engineering undergraduates from a single Materials Science and Engineering laboratory. There were four undergraduates who did not participate: one because of academic demands, another (a graduating senior) who was focused on academic and post-graduate plans and the final two (freshmen) who joined the group midway through the quarter. Of the eight students participating in the study, four of the undergraduates were already paid the minimum hourly stipend to conduct research, two received course credit for participation, and two were volunteers. There was one sophomore, five juniors, and two seniors participating in this study. All of the undergraduates had been participating in this research lab for at least three quarters prior to the start of this study. The grade point average of these undergraduates ranged from 2.5 to 3.8, with an average verbal SAT score of 545.63 ($SD = 67.48$) and an average quantitative SAT score of 601.25 ($SD = 63.12$). Seventy-five percent of the undergraduates expressed interest in pursuing graduate studies in engineering.

Materials

There are two measures included in this study: a weekly survey of undergraduate research activities and an assessment of undergraduates' communication skills. The online weekly survey asked students to provide the number of hours spent engaging in each of the 11 activities ($\alpha = 0.82$). In addition, students were asked to complete two dichotomous items to indicate whether or not undergraduates received guidance or help from a graduate student or faculty member, ($\alpha = 0.90$) and whether or not undergraduates had any input or opportunity to share their ideas for each of the 11 research activities ($\alpha = 0.96$). For example, if the undergraduate spent time conducting an experiment, they were asked to indicate whether or not they received help in conducting this experiment from a graduate student or faculty member. In addition, they were asked whether the graduate student or faculty member was receptive to the undergraduate sharing their thinking about how the experiment was conducted.

To gather evidence of validity for the weekly survey, graduate students who supervised the particular undergraduates were shown survey responses and asked to comment on whether the responses reflected their perceptions of how the undergraduates spent their time and the amount of input the undergraduate had in the various activities. The graduate students generally agreed that the undergraduate student responses were representative of the types of activities the undergraduate students were engaged in. In addition, several of the undergraduates were individually interviewed at the end of data collected from the weekly surveys to assess the quality of the survey information and asked to revise or modify any discrepancies in their responses. Some undergraduates felt that they underestimated the amount of time spent conducting research because there were times when they were thinking about their research, but not necessarily actively working on any particular aspect (for example, while riding their bike to school). Other undergraduates said that they wanted more open-ended response options instead of the categorical responses. However, overall, the undergraduates agreed that the responses were representative of the activities they participated in. Talking with the graduate and undergraduate students provided assurance that the information provided online was an accurate representation of the undergraduates' research experiences for the 10 weeks.

Table 1 provides the items describing each of the activities. These activities

	Metric			
	Hours Spent	*Mentoring Received*	*Opportunities to Share*	*Mentoring Received and Opportunity to Share*
1. Preparing for an experiment	32.88 (24.24)	4.88 (2.80)	4.00 (2.98)	2.25 (1.98)
Understanding a scientific journal article	8.38 (4.88)	1.13 (1.36)	1.25 (1.75)	0.38 (0.52)
Designing an experiment	7.13 (5.41)	3.25 (2.49)	2.88 (2.64)	0.63 (0.52)
Understanding the purpose of the experiment in relation to the larger research project	6.13 (5.59)	2.38 (2.45)	1.62 (1.92)	0.50 (0.54)
Learning how to do an experiment	6.50 (6.39)	2.38 (2.13)	0.88 (1.73)	0.25 (0.46)
Understanding why the experiment is set up and conducted in a particular way	4.75 (5.55)	2.00 (2.20)	1.25 (2.38)	0.50 (0.54)
2. Conducting an experiment	40.13 (26.76)	2.25 (2.38)	2.88 (3.48)	0.75 (0.89)
Conducting an experiment	34.50 (22.32)	1.88 (2.10)	2.75 (3.37)	0.38 (0.52)
Problem solving or troubleshooting	5.63 (6.55)	1.50 (2.33)	1.88 (2.64)	0.38 (0.52)
3. Interpreting data	20.75 (21.24)	1.75 (2.38)	2.38 (3.02)	0.50 (0.93)
Manipulating data (plotting, creating pictures)	11.75 (14.78)	1.13 (1.55)	2.00 (2.88)	0.25 (0.46)
Analyzing, interpreting data	9.00 (7.56)	1.38 (1.77)	2.00 (2.88)	0.25 (0.46)
4. Presenting findings	20.63 (12.05)	2.50 (2.39)	3.13 (2.47)	1.13 (0.99)
Preparing an oral/poster presentation	15.75 (8.75)	1.63 (1.77)	2.38 (1.92)	0.63 (0.52)
Writing manuscript	4.88 (5.11)	1.38 (1.41)	1.50 (1.41)	0.50 (0.54)

Note. Standard deviations in parentheses.

Table 1. Descriptives Statistics of Research Activities ($n = 8$)

were combined into four variables: preparing for an experiment, conducting an experiment, interpreting data and sharing findings. We examine these four variables using four different metrics to describe the structure and intensity of the undergraduates' research experiences. The first metric examines the total number of hours spent conducting these four activities and how they influence communication skills (metric 1). The second metric considers the amount of mentoring received from a graduate student or faculty member. This metric is calculated based on the total number of weeks during which the undergraduate indicated that they received help or guidance from a graduate student or faculty member (metric 2). The third metric considers the amount of opportunities undergraduates were provided to share their thinking on each of the research activities. This metric is calculated based on the total number of weeks during which the undergraduate indicated that they were asked to share their thinking with a graduate student or faculty member (metric 3). The fourth metric considers whether students received both mentoring and the opportunity to share for more than one week (metric 4). Examining these four research activity variables with these four different metrics provides information about what research activities students engage in and whether these activities relate to communication skills.

The second measure is an outcome measure that describes the undergraduates' communication skills. This measure was also piloted in the previous summer and is based on the Accreditation Board for Engineering and Technology, Inc. (ABET) standards for oral presentations. This measure is also used for oral presentations throughout this college of engineering. There were three components included in this measure: content, structure and delivery. Content refers to the substantive portion; structure refers to the organization, and delivery refers to the verbal expression of the presentation. Raters evaluated each of the undergraduates on a four-point scale for each component. Example statements for each score point were provided to raters. An example of the highest level for content include: The purpose is clear and responds to audience's expectations, goals, knowledge and purpose; Ideas are well developed, and points are selective and supported.

Procedures

Weekly survey data of research activities were collected from undergraduates during the spring 2011 quarter. Undergraduates received an email with a link to the online survey each Friday morning. The weekly survey took less than five minutes to complete and was collected online for 10 weeks. If an undergraduate did not complete the survey within two days of the initial email, a reminder email was sent. All students completed the survey after the reminder.

At the end of the quarter, the undergraduates presented their work at a local museum. The museum is a learning center that collects, exhibits and interprets cultural and natural history. There were approximately 150 visitors to the museum on the date of the students' presentations. The undergraduates created posters and hands-on demonstrations to help share their research with museum visitors. Prior to their presentations, the museum curator spoke to the undergraduates about informal science education and another museum official critiqued the undergraduates' posters and hands-on demonstrations. The undergraduates' presentations were evaluated by a random sample of 20 visitors. Visitors who agreed to provide ratings of the undergraduates' presentations were provided with $10 gift cards. These raters were given a brief introduction to the purpose of their ratings and the three components of the communication skills outcome measure. Raters were also asked to self-report their ethnicity, gender, age, and level of science content knowledge (expert, proficient, competent, beginner, or novice). Although data was obtained from a random sample of 20 visitors, many of the visitors indicated that they did not have sufficient content knowledge to be able to accurately evaluate the undergraduates' presentations. All of the visitors who rated themselves as proficient, competent, beginner, or novice gave the highest score to all undergraduates on all three components (content, structure, and delivery). Given the lack of variation in the scores from the non-experts, only the scores from the two raters who indicated that they were experts were used as the final outcome measure. The final outcome measure was based on a combination of the two scores from the expert raters with a possible range of 0-100.

Results

Descriptive statistics for the average number of hours for each research activity are presented in Table 1. On average, students spent the largest amount of time conducting experiments and the least amount of time understanding why experiments were set up and conducted in a particular way. There were differences in terms of the structure of the undergraduates' research experiences. All students received some sort of mentoring and the opportunity to share for at least one activity across the 10 weeks. However, there was variation between students in terms of which activities they received mentoring and which activities they received the opportunity to share their ideas. Some students received more mentoring and the opportunity to share compared to other students both in terms of the number of weeks and the types of activities.

There was also variation in terms of whether students received both mentoring and the opportunity to share for the same activity. On average, there were more opportunities where undergraduates reported receiving both mentoring and the opportunity to share during activities that involved preparing for an experiment ($M = 2.25$, $SD = 1.98$) compared to the other three activities. There were only two students who had more than a week of mentoring and the opportunity to share their thinking on how to interpret results from an experiment.

Based on repeated measures analysis of variance, there were statistically significant differences between the research activities that students participated in, and which research activities they participated in from week to week (Table 2). The differences between students were consistent using different metrics for each research activity, but less consistent when

Research Activity	*Metric*	*Differences Between Students (n = 8)*	*Differences Between Weeks (n = 10)*
1. Preparing for an experiment	Number of hours spent	9.51***	1.58
	Mentoring received	4.07***	1.36
	Opportunity to share	5.29***	1.63
	Mentoring received and opportunity to share	8.83***	1.19
2. Conducting an experiment	Number of hours spent	9.67***	2.52*
	Mentoring received	4.28***	1.43
	Opportunity to share	12.45***	2.01
	Mentoring received and opportunity to share	12.49***	1.36
3. Interpreting data	Number of hours spent	8.83***	2.05*
	Mentoring received	5.64***	1.44
	Opportunity to share	7.68***	0.57
	Mentoring received and opportunity to share	6.53***	1.19
4. Presenting findings	Number of hours spent	2.23*	4.44***
	Mentoring received	4.65***	2.94**
	Opportunity to share	4.02**	2.42*
	Mentoring received and opportunity to share	4.77***	2.43*

*$p < .05$. **$p < .01$. ***$p < .001$.

Table 2. Differences in the Structure and Intensity of Research Activities Between Students and Between Weeks

considering differences between weeks. In other words, there were differences between the eight students in terms of what sort of research activities they engaged in and the amount of mentoring and opportunities to share they were afforded for each research activity. The differences for these eight students across the 10 weeks were less consistent. In terms of differences between weeks, we found statistically significant differences in the total number of hours spent conducting experiments, interpreting findings and presenting findings. There were also statistically significant differences between weeks in terms of the amount of mentoring and opportunities to share that occurred in regards to presenting findings.

	1.	2.	3.	4.	5.
1. Preparing	- - -				
2. Conducting	0.45	- - -			
3. Interpreting	0.39	0.87	- - -		
4. Presenting	0.71*	0.69	0.54	- - -	
5. Communication	0.38	0.78*	0.70*	0.49	- - -

*$p < .05$.

Table 3. Correlations Between Research Activities With Mentoring and Opportunities to Share Metric; and Communication Skills ($n = 8$)

To help explore the relationship between the different research and communication skills, we ran separate correlations for each metric. There were no significant correlations between the amount of time spent on any of the research activities (metric 1), opportunities for mentoring (metric 2) or the opportunities for sharing (metric 3) and communication skills. However, when considering particular types of research activities and sustained mentoring and sharing opportunities (metric 4), there are significant relationships (Table 3). Students with greater mentoring and opportunities to share ideas when conducting an experiment ($r(6) = .78, p < .05$) and interpreting data ($r(6) = .70, p < .05$) had significantly higher communication scores. There were no significant correlations in terms of preparing for an experiment and presenting findings.

Discussion and Conclusions

This study quantifies the structure and intensity of undergraduates' participation in research and relates this information to undergraduates' public communication skills. Students examined in this study varied in terms of the types of research activities they engaged in. Using four different metrics of self-reported measures of four types of research activities (preparing, conducting, interpretin, and presenting), there were differences between students and across weeks. There were also differences in terms of how much time was spent on different research activities. These differences occurred between students as well as between the 10 weeks students were observed. Moreover, there were differences in terms of how much support or guidance students received and how often students were able to share their thinking on particular research activities. The research activities and environments that most positively and significantly related to communication with a diverse audience were conducting experiments and interpreting research findings. In these two activities, there was extended interaction between the undergraduate and graduate student as well as extended opportunities for undergraduates to actively contribute to the interaction.

This study shows that requiring undergraduates to conduct a certain number of hours of research per week, or mandating participation in particular types of research activities each week, does not relate to the undergraduates' ability to communicate their research with a diverse audience. While it is important to provide opportunities to participate in a range of research activities, from preparing to conduct an experiment to writing up the findings, this is a necessary, but not sufficient condition that supports the development of undergraduate engineering students' communication skills. In addition, only providing mentoring opportunities or only providing opportunities to share their thinking is not a sufficient condition. If, however, both mentoring and sharing opportunities jointly occur for an extended period of time, this type of working condition relates to more effective communication with a diverse audience. In particular, we find a positive and significant relationship between communication scores and students who received both mentoring on research activities related to conducting and interpreting experiments, and the opportunity to share their thinking across more than a single week. This significant relationship supports the notion of students being active participants in the research process and the need to be in ongoing supportive environments. Thus, it is imperative that there is sufficient guidance and mentoring from a graduate student or faculty member and that undergraduates have the opportunity to share their ideas or thoughts on these activities.

Given the importance for future engineers to be effective communicators of their work with a diverse audience, identifying specific activities that can be influential to developing this skill is critical. This study provides insights in terms of the specific undergraduate activities and intensive research environments that can be beneficial to future engineers. This study is limited in terms of the sample size and the self-selected nature of the undergraduates who participate in undergraduate research. However, the study collects detailed and consistent information about student participation in various research activities and relates this information to students' public communication skills. Future research could address this limitation by including other materials science and engineering research groups. This larger sample size will allow for description of the variation within and between research groups. Future research could also collect more detailed information about the selection mechanism into particular materials science research groups and include multiple measures of pre-existing differences between groups and students.

References

AAAS. (2011). Communicating science: *Tools for scientists and engineers.* Washington, DC: Author. Retrieved on September 1, 2011 from http://communicatingscience.aaas.org/

Cox, M. F., & Andriot, A. (2009). Mentor and undergraduate student comparisons of students' research skills. *Journal of STEM Education: Innovations and Research, 10*, 31-39.

Kalonji, G. (2005). Capturing the imagination: High-priority reforms for engineering educators. In National Academy of Engineering (Ed.), *Educating the engineer of 2020: Adapting engineering education to the new century* (pp. 146–150). Washington, DC: National Academies Press.

Sadler, T. D., Burgin, S., McKinney, L., & Ponjuan, L. (2010). Learning science through research apprenticeships: A critical review of the literature. *Journal of Research in Science Teaching, 47*(3), 235-256.

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

Zydney, A. L., Bennett, J. S., Shahid, A., & Bauer, K. W. (2002). Impact of undergraduate research experience in engineering, *Journal of Engineering Education, 91*(3), 151-157.

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