

Incorporating Complexity into Undergraduate Engineering Development through the Research Communications Studio

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Introduction

The National Academy of Engineering's Engineer of 2020 project addressed the growing need to pursue collaborations with multidisciplinary teams of experts, because of the increasing complexity and scale of systems-based engineering problems¹⁵. These teams must be able to communicate effectively with technical and non-technical people, to use technology to enhance communication, and to understand the complexities that are associated with the social, environmental, and technical aspects of their work.

Through the communications approach, the RCS seeks to enhance students' cognitive development. Herbert Simon points out that the basic principle of the enterprise of cognitive studies is that "learning takes place inside the learner and only inside the learner".¹² However, Simon also recognizes that "whether from books or people, at least 90% of what we have in our heads . . . is acquired by social processes, including watching others, listening to them, and reading their writings". The RCS takes into account this socially distributed nature of learning by building an optimal environment for research learning to occur. The learners' knowledge construction process is aided by an environment of distributed cognition in which participants at all levels—experts, mentors, accomplished novices, and novices—teach and learn from each other.⁴ The RCS addresses the development of communications abilities in a system of distributed cognition.

Survey results of RCS participants are presented to provide an example of a way to incorporate complex systems study into the existing undergraduate engineering curriculum. Complex systems study is defined as a new field of science that studies the collective behavior of a system and how this system interacts with its environment. Complex systems study is laying the foundation for a revolution of all sciences to move beyond reductionism into holism.⁷ The undergraduate RCS students are forced to move from reductionistic thinking into holistic thinking.

They must explain their research to students in different research groups, to students from different engineering disciplines, to an engineering mentor, to a linguistics graduate student, and to an English professor. By communicating their research to this varied audience, the students are forced to think about how their research fits in the 'bigger picture.'

A method for determining whether the undergraduate students have become better communicators and complex systems thinkers will be discussed. The first part of this method involves pre- and post-semester surveys taken by the RCS students. The results of this survey

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indicate that students who participated in weekly RCS sessions are better complex systems thinkers. This was demonstrated by the students' perceptions of themselves as better communicators after participation in the RCS. These findings are consistent with previous findings.⁸

Research Communications Studio Approaches

The RCS nurtures undergraduate learning in engineering through guided interaction among student peers, near-peer graduate mentors, and faculty members. The RCS bases its pedagogical approach on Dorothy Winsor's concept of thought and knowledge as a network distributed among members of a group with shared goals.¹⁶ Possessing various levels and aspects of expertise, the RCS staff and students together construct knowledge by communicating their understanding—or gaps in understanding—of the participating undergraduates' research and related deliverables during the small, weekly meetings of interdisciplinary studio groups. Figure 1 shows the interactive relationship among the interdisciplinary staff and undergraduates along with the connection of all participants to the engineering faculty members.

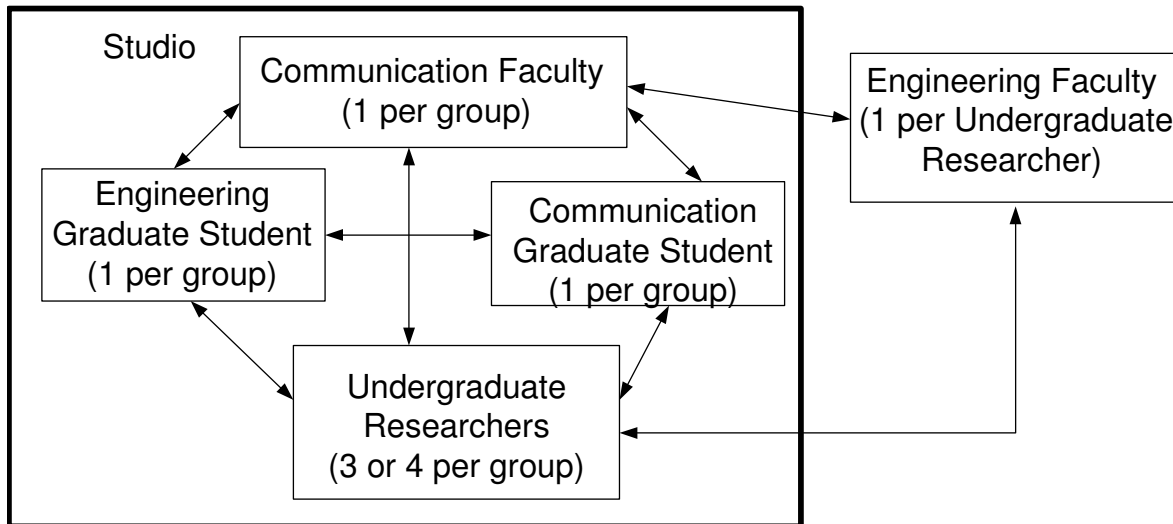


Figure 1--The network of participants

The RCS also bases its pedagogical approach on metacognition. Metacognition refers to the student's ability to predict their performance on different tasks and to monitor their understanding of a certain task.⁴ During the RCS sessions students are often asked to verbalize how they learned something. This helps the student monitor their understanding and learning. They are also required to write a reflection on what they learned and what they are going to do next after each weekly session. This helps them hone their metacognitive skills.

At the beginning of the semester, the students are required to develop a task plan with the help of their advisor. This task plan spells out the specific deliverables that are to be completed before the end of the semester. These deliverables are then evaluated by the University of South Carolina's Office of Program Evaluations (OPE). The OPE staff uses a rubric that was created specifically for this purpose.⁸ For each meeting, undergraduates bring a draft of one of their deliverables. The participants' work, which can include a variety of reports, presentations,

journal articles, posters, Web sites, or other technical genres, provides the content for the Studio sessions. Students have the opportunity to discuss their research projects with peers, near peers, and professionals, to find out how interested audiences respond to their work, and to receive helpful feedback as they develop their writing and presentation abilities.

A large part of the RCS involves research that takes place in the context of the RCS studio. The English professors, linguistics graduate students, and graduate engineering mentors conduct research that is aligned with their research interests and is placed within the context of the RCS studio.^{2, 5, 9, 10, 11} Much of the data that is regularly collected involves surveys that the RCS group members and the research advisors complete. This data is collected and reported by the OPE. The first author on this paper has an interest in complex systems study and has integrated this into the RCS by conducting pre- and post-surveys that are discussed in detail throughout the rest of this paper.

Survey Methodology

Sample

Ten students participated in the RCS during the fall semester in 2004. These students were nominated by their research faculty advisors. They were also required to be signed up for an hour of research credit. These students are compensated financially with a \$450 stipend per semester.

Responses from all 10 students are included in this study. Most of the students are from the chemical engineering department (6), while some are from the mechanical engineering department (3) and the remaining student is from the electrical engineering department. Of these 10 participants, 6 are women and 4 are men. Five students had participated in the RCS previously, while 5 had not.

Pre- and post-Surveys

The online survey was developed using CTL Silhouette featuring the Flashlight™ Current Student Inventory Version 2.9. The survey questions were developed cooperatively by the research team. Radio buttons were used for questions 1-4 (See Figure 2). Only one radio button could be activated at a time. The Likert scale that was used for questions 5-26 offered options of “Strongly Disagree”, “Disagree”, “Agree”, “Strongly Agree”, and “Not Applicable” (See Figure 3)³.

The objective of questions 1-4 and 25 was to collect demographic information. This included how many semesters the students have done research, how many semesters they participated in the RCS, how many years they have been in college as undergraduates, whether their research this semester is an extension of research from previous semesters, and whether they plan to present or publish part of their research in the next 5-10 months.

The objective of questions 5, 6, and 13 was to determine how well the students believe that they understand their research. These questions are metacognitive in nature, because they require the students to judge how well they understand their research areas. These questions include how

well they understand their research project, the subject matter that their research is a part of, and the ‘bigger picture’ of their research.

The objective of questions 7- 9, 18, 20-24, and 26 was to determine whether the students progress from the novice researcher to a more experienced researcher. Some of these questions (20, 21, 24, and 26) targeted this progression from a novice to a more experienced researcher with an emphasis on the student/ advisor relationship. These questions included whether the students will be able to transfer the skills that they have learned during this research experience into other research projects, whether they are better researchers as a result of this experience, whether they perceive themselves to be novices or experts in their field of research, whether they have researched pertinent literature to find solutions to research problems, whether they find it difficult when their research is not going as was planned, whether they wait for instructions from their advisor before they begin working, whether they regularly ask their advisor questions pertaining to their research, whether they believe that their advisor knows what the outcome of their research will be, and whether they routinely communicate with their advisor about their plans for developing their research.

The objective of questions 10 and 19 was to determine whether the students become more effective team members as a result of their experience in the RCS. These questions included how well the students work in the team environment and whether they are comfortable giving criticism or praise to their peers.

The objective of questions 11, 12, and 14-17 is to determine whether the RCS participants’ communication skills improve as a result of a semester in the RCS. These questions include whether the students have trouble describing their research with words, whether the students find it useful to draw a picture when describing their research to others, and whether the students feel comfortable telling other engineering students, friends, family, and engineering professors about their research.

The 10 subjects were surveyed online at the beginning and end of the semester. A paired t-test was used to compare the survey responses of the students before and after the semester. The results of the paired t-test were considered to be significant if they were less than .1. This provides a confidence interval of 90%. If they were greater than .1 the populations were considered to have no difference before and after the semester. The results were also analyzed after dividing the subjects into a group of students that have participated in the RCS previously, and a group that have not participated in the RCS previously. These results were also analyzed using a paired t-test.

1. How many semesters have you done research as an undergraduate (count summer as one semester)?
2. How many semesters have you participated in the RCS?
3. How many years have you been in college as an undergraduate?
4. My research this semester is an extension of research from previous semesters.

Figure 2--Questions 1-4 with Radio buttons for responses

5. I have a good understanding of my research project.
6. I have a good understanding of the subject matter of the area that my research is in.
7. I will be able to transfer the skills that I have learned during this research experience into different research projects.
8. I am a better researcher as a result of my research experience.
9. I consider myself to be an expert in my field of research.
10. I work well in teams.
11. When describing my research to others I have trouble describing it with words.
12. When describing my research to others I find it useful to draw a picture.
13. I understand the 'bigger picture' of my research.
14. I feel comfortable telling other engineering students about my research.
15. I feel comfortable telling my friends about my research.
16. I feel comfortable telling my family about my research.
17. I feel comfortable telling my engineering professors about my research.
18. I consider myself to be a novice in my field of research.
19. I feel comfortable giving criticism or praise to my peers.
20. I wait for instructions from my advisor before I begin working.
21. I regularly ask my advisor questions pertaining to my research.
22. I research pertinent literature to find solutions to my research problem.
23. I find it difficult when my research is not going as planned.
24. I believe that my advisor knows what the outcome of my research will be.
25. I plan to present or publish part of my research in the next 5-10 months
26. I routinely communicate with my advisor about my plans for developing my research.

Figure 3--Questions 5-26 with Likert scale responses

Survey Results and Discussion

The results of this survey indicated that the RCS students perceive themselves as being better complex systems thinkers. This was demonstrated in their improved perceptions of their metacognitive and communicative skills. These results were statistically significant.

The results of the questions that collected demographics from the students will be discussed first (questions 1-4 and 25). The students had conducted research for an average 2.4 semesters before the fall 2004 semester. Specifically 2 students had not conducted any previous research, while 3 students had conducted 4 semesters of research. The students participated in the RCS an average of 0.6 semesters. Exactly half of the students had not participated in the RCS before; of those students 4 had participated in the RCS for 1 semester, while 1 had participated for 2 semesters.

The students have been in college for an average of 2.4 years. Half of the students were continuing a research project from a previous semester. The majority (8) of the students plan to publish or present their research in the next 5 – 10 months.

The questions that determine how well the students understand their research indicate that the students feel more comfortable with the topics of their research after a semester of RCS participation (questions 5, 6, and 13). On students' better understanding of their research, there is a statistically significant difference between the responses before and after the semester (See Figure 4). However, when the students are divided into the groups that have RCS experience and those that do not, the responses of the students that have RCS experience are not statistically significant, while the responses of the students that have no RCS experience are statistically significant (See Figure 5). This indicates that the students who had previously participated in the RCS had already begun to progress to a better understanding of the role of communication and metacognitive skills in their research. The question that addresses how well the student's understand the 'bigger picture' of their research has a statistically significant difference between the responses of the whole group before and after the semester and the students with no RCS experience before and after the semester.

There is some evidence that the students that participated in the RCS progressed from novice researchers to more experienced researchers (questions 7- 9, 18, 20-24, and 26). The responses moved away from agree towards disagree in response to the question that asked the students if they waited for instructions from their advisors before beginning to work. Assuming truthful responses, this indicates that the RCS students are maturing as researchers. There was a significant difference in the responses of the entire group of students (See Figure 4) and in the responses of the students with no prior RCS experience (See Figure 5). There was also a significant difference in the results of the students with no prior RCS experience for the question that addressed whether the students believe that their advisor knows what the outcome of their research will be.

There was no significant difference in the results of the questions that determined if students became better team members after the semester of RCS (questions 10 and 19).

The results indicated that the RCS participants' communication skills improved after a semester as a participant in the RCS studio sessions (questions 11, 12, and 14-17). The question that addressed whether the students find it useful to draw a picture when describing their research to others had a significant difference in the results for the group as a whole (See Figure 4) and for the students with no prior RCS experience (See Figure 5). This shows that the student's communication skills have increased, because of their ability to describe their research using drawings. The questions that addressed whether students feel comfortable telling other engineering students and friends about their research yielded statistically significant differences for the entire group (See Figure 4) and for the students with no prior RCS experience (See Figure 5). The question that addressed whether students feel comfortable telling their family about their research did not yield significant differences in the results; however there was an increase in the average response (See Figure 4 and Figure 5).

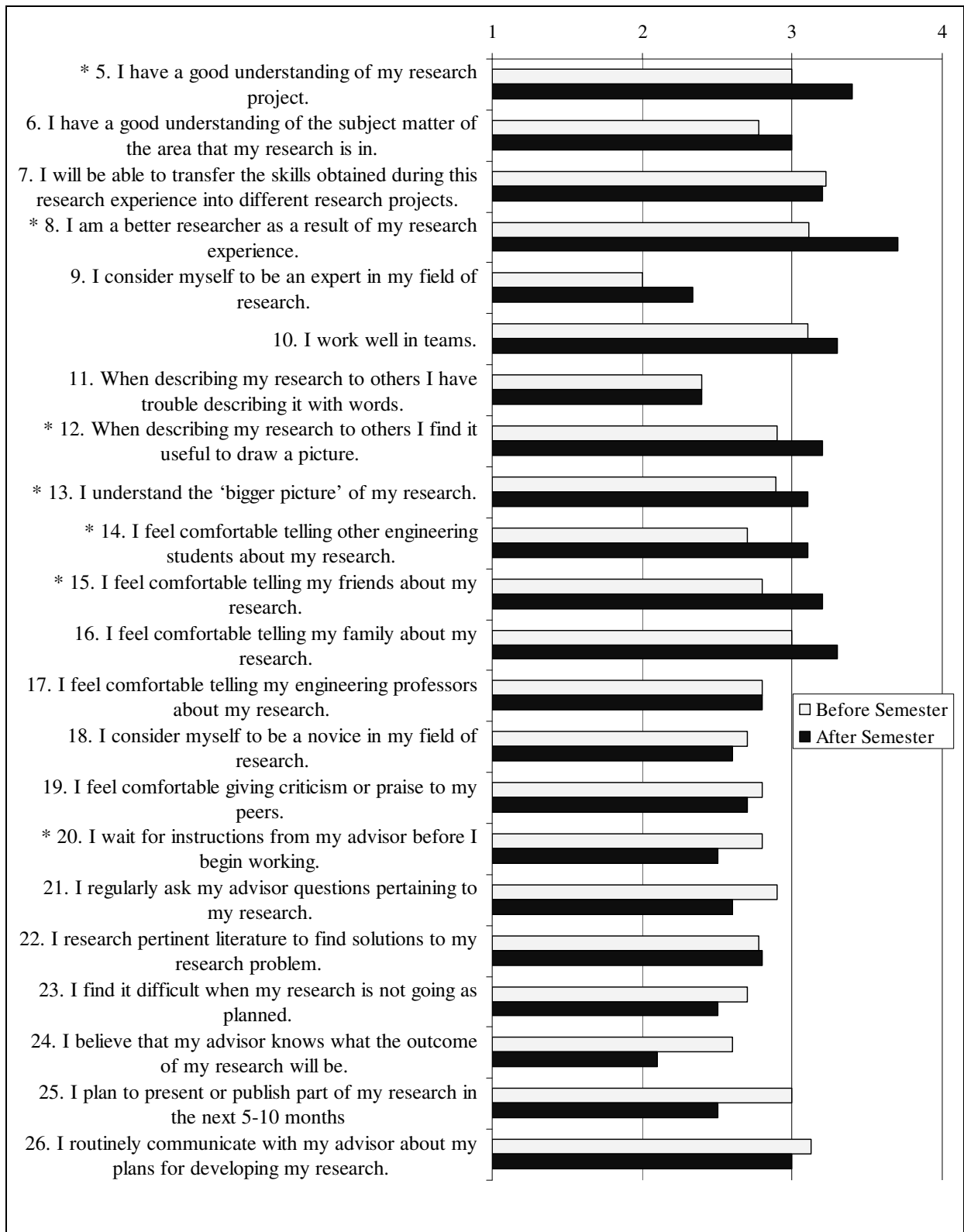


Figure 4—Results, * denotes a statistically significant difference in the responses before and after the semester, 1 --“Strongly Disagree,” 2 -- “Disagree,” 3 -- “Agree,” 4 -- “Strongly Agree”

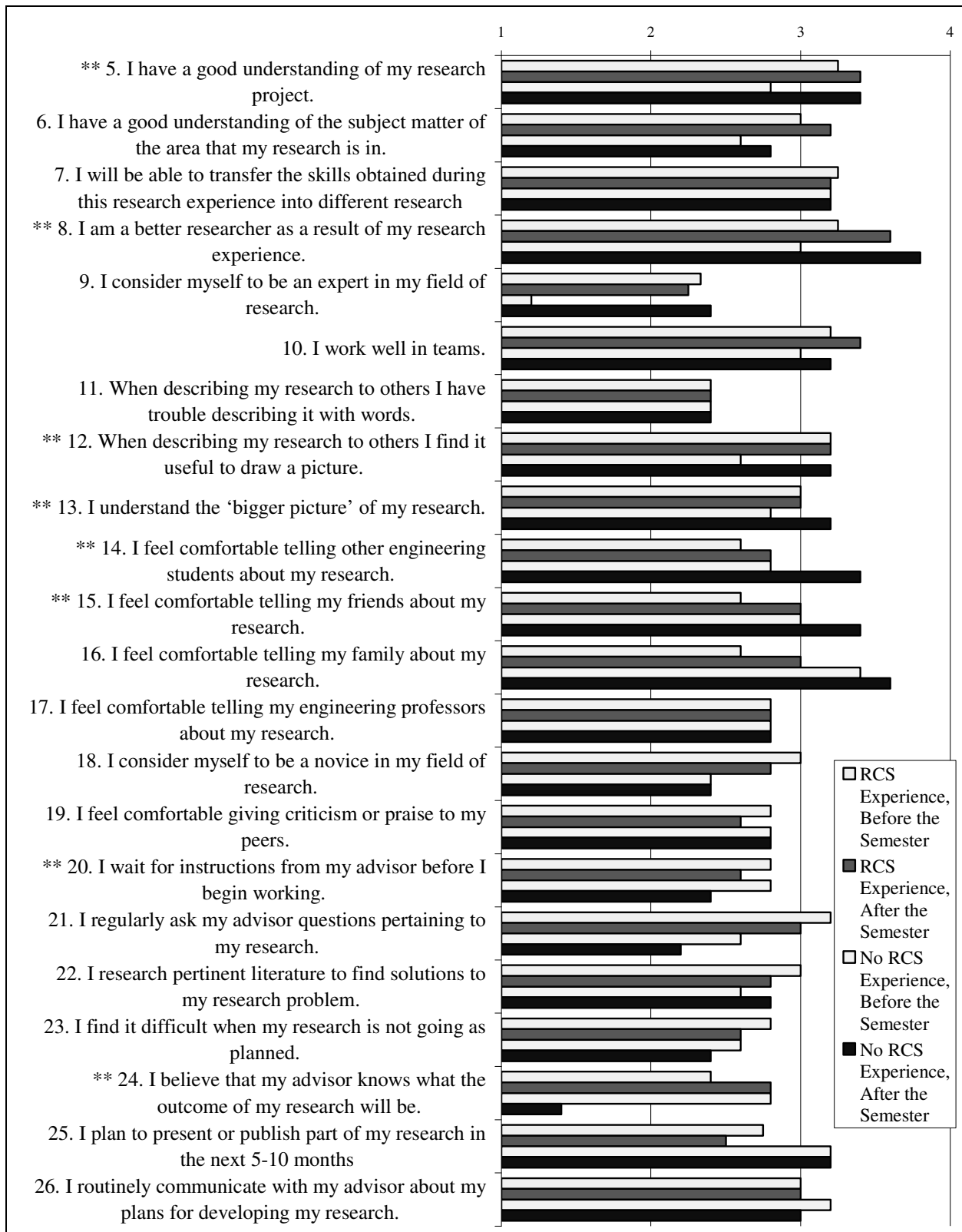


Figure 5--Results separated by students with RCS experience and those without RCS experience, ** denotes a statistically significant change in the student's responses without RCS experience before this semester, 1 -- "Strongly Disagree," 2 -- "Disagree," 3 -- "Agree," 4 -- "Strongly Agree"

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These data show that the RCS provides a vehicle to introduce engineering students to complex systems study. The undergraduate engineering students learn the importance of communication and metacognitive skills in truly understanding their research and conveying this understanding to people from different disciplines. The results of the pre- and post-surveys indicate that the undergraduate RCS students showed a statistically significant improvement in their perceptions of their communication and metacognitive skills. These findings are consistent with previous findings that showed an improvement in deliverable quality over 2 semesters.⁸

Future Work

This research could be expanded by having undergraduate researchers that are not in RCS take this survey before and after a semester of conducting research. It would be interesting to compare the results of students that participate in the RCS to those that do not.

The RCS program has collected data that could be analyzed to triangulate the data presented in this paper. This data include excerpts taken from the student's weekly reflections, the OPE report on deliverable quality, and the advisor's comments from mid-semester meetings with the English professor, linguistics graduate student, and the engineering graduate student. The latter gives the perspective of the advisor, who has usually worked with students who have participated in the RCS and with students who have not participated in the RCS.

Conclusion

The RCS provides an innovative way to connect communication skills with engineering research. The pre- and post-survey that was presented in this paper showed evidence that RCS students' perceptions of their communication and metacognition skills increased.

Evans, et al explained the results of a survey that was completed by engineering employers and engineering alumni.⁶ "But both the industry group and the alumni rated communication skills, professionalism and ethics, and a responsible and open mind, above both depth and breadth of technical skills, and math and science skills. This is indicative of the mounting evidence that employers, especially those that are joining or that have joined the quality revolution, are desperate for people who do not have to learn on the job how to fit into a team-centered culture where communication, interpersonal skills, and professionalism, are as important as technical skills." This is not a new problem. In 1918, the Carnegie Foundation reported a similar concern from industry: "The professional criticisms of the schools indicate that this field offers the greatest opportunity for effective changes in current practice, because lack of good English, of business sense, and of understanding of men are most frequently mentioned by practicing engineers as points of weakness in the graduates of the schools." The RCS provides a small group learning environment that stresses the importance of communication within the context of undergraduate research.

There is a need for a change in the current engineering curriculum. The complexities of the systems that we "engineer" are beginning to be understood because of the many breakthroughs in science. There is a desire among many of the leaders in engineering to address these complexities in the undergraduate engineering development programs. The Accreditation Board of Engineering Training addresses this need in the current accreditation method, Criteria 2000. It

states that the graduates must possess the broad education necessary to understand the impact of engineering solutions in a global and societal context.¹ Complex systems study addresses this, because it deals with not only the technical aspects of a system, but the global, societal, economical, and environmental aspects as well. The RCS small-group learning approach is a start to developing a complex systems oriented method of educating our future engineers.

There is evidence that the RCS helps undergraduate engineering students see the 'bigger picture' of their research through explaining their research to a technical and non-technical audience. "No idea is fully formed until it can be communicated. ...The organization required for writing and speaking is part of the thought process that enables one to understand material fully."¹⁴ These words from the Boyer Commission Report express the importance of communication in helping the learner to truly understand their material on a broader scale.

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Biography

NADIA CRAIG is currently conducting research in the Laboratory for Sustainable Solutions while completing her Ph.D. in mechanical engineering. Her research interests include engineering education, sustainable design, and complex systems science. Her dissertation, “Integrating Complex Systems Study into Engineering Education” involves benchmarking engineering education in the US against Australia and developing a way to incorporate complex systems study into engineering education. She is a recipient of the National Science Foundation’s Graduate Research Fellowship.

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