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 problems[1]. 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.

The RCS is an approach to developing the engineering and communications skills of undergraduate students through the avenue of research. An engineering graduate student mentor, a linguistics graduate student, an English faculty member, and 3 to 4 engineering undergraduate researchers meet weekly to work on all aspects of communication directly connected to their research. The undergraduate researchers are from chemical, mechanical, and electrical engineering. This team's work is based on the following learning theories: near-peer learning, metacognition, and distributed cognition. By embracing these learning theories in a multidisciplinary team, any team could reap the benefits that have been observed in the RCS.

A case study of the Research Communications Studio (RCS) is presented to provide an example of a way to incorporate complex systems study into the existing undergraduate engineering curriculum. The method for determining whether the undergraduate students have become better communicators and complex systems thinkers will be discussed. This method involves pre and post semester surveys taken by the students. The results of this survey indicate that students that participated in weekly RCS sessions become better complex systems thinkers. This was demonstrated in their improved metacognitive and communicative skills.

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 nontechnical 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[2]." 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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Methodology

Sample

There were 10 RCS participants during the fall semester in 2004. 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 FlashlightTM 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 1). Only one radio button can 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 2).

The objective of questions 1-4 and 25 is to collect demographic information. This includes how many semesters they have done research, how many semesters they have participated in the RCS, how many years they have been in college as an undergraduate, 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 is 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 is to determine whether the students progress from the novice researcher to a more experienced researcher. Some of these questions (20, 21, 24, and 26) target this progression from a novice to a more experienced researcher with an emphasis on the student/ advisor relationship. These questions include whether the students will be able to transfer the skills that they have learned during this research experience into other research projects, are better researchers as a result of this experience, consider themselves to be novices or experts in their field of research, research pertinent literature to find solutions to their research problems, find it difficult when their research is not going as was planned, wait for instructions from their advisor before they begin working, regularly ask their advisor questions pertaining to their research, believe that their advisor knows what the outcome of their research will be, and routinely communicate with their advisor about their plans for developing their research.

The objective of questions 10 and 19 is to determine whether the students become more effective team members as a result of their experience in the RCS. These questions include how well the

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students work in team environment and whether they feel comfortable giving criticism or praise to their peers.

The objective of questions 11, 12, and 14-17 is to determine whether the RCS participant's 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 before and after 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 gives us 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 has 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 1--Questions 1-4 with Radio buttons for responses

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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 2--Questions 5-26 with Likert scale responses

Results and Discussion

The results of this survey indicate that students that participated in weekly RCS sessions become better complex systems thinkers. This was demonstrated in their improved metacognitive and communicative skills.

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; 4 students had participated in the RCS for 1 semester, while 1 student had participated in the RCS for 2

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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 understand their research and the bigger picture of their research better after the fall semester (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 3). 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 4). 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. There was a significant difference in the responses of the entire group of students (See Figure 3) and in the responses of the students with no prior RCS experience (See Figure 4). 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 indicate that the RCS participant's communication skills improve 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 3) and for the students with no prior RCS experience (See Figure 4). 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 3) and for the students with no prior RCS experience (See Figure 4). 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 3 and Figure 4).

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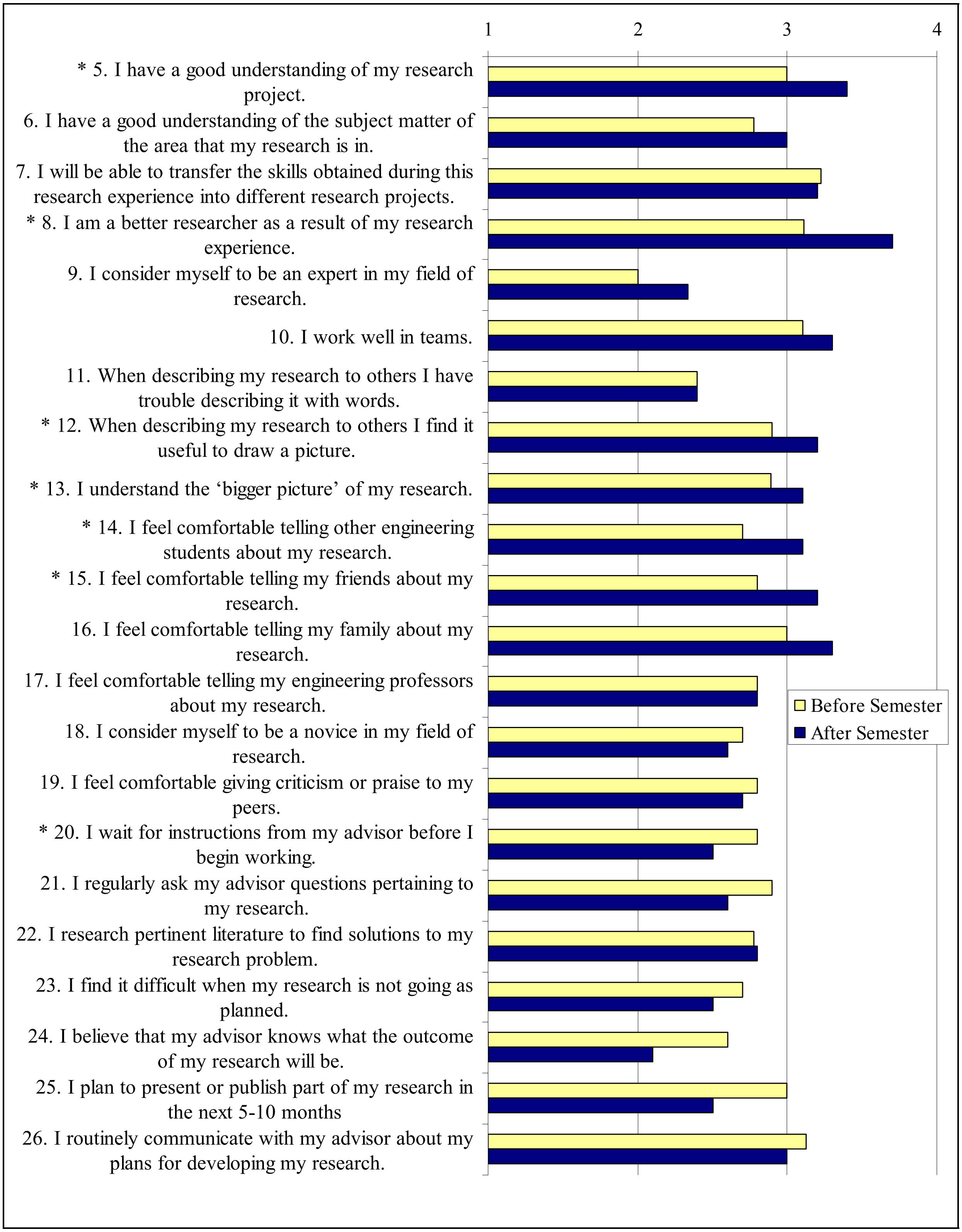

Figure 3—Results, * denotes a statistically significant difference in the responses before and after the semester, 1 --"Strongly Disagree," 2 -- "Disagree," 3 -- "Agree," 4 -- "Strongly Agree"

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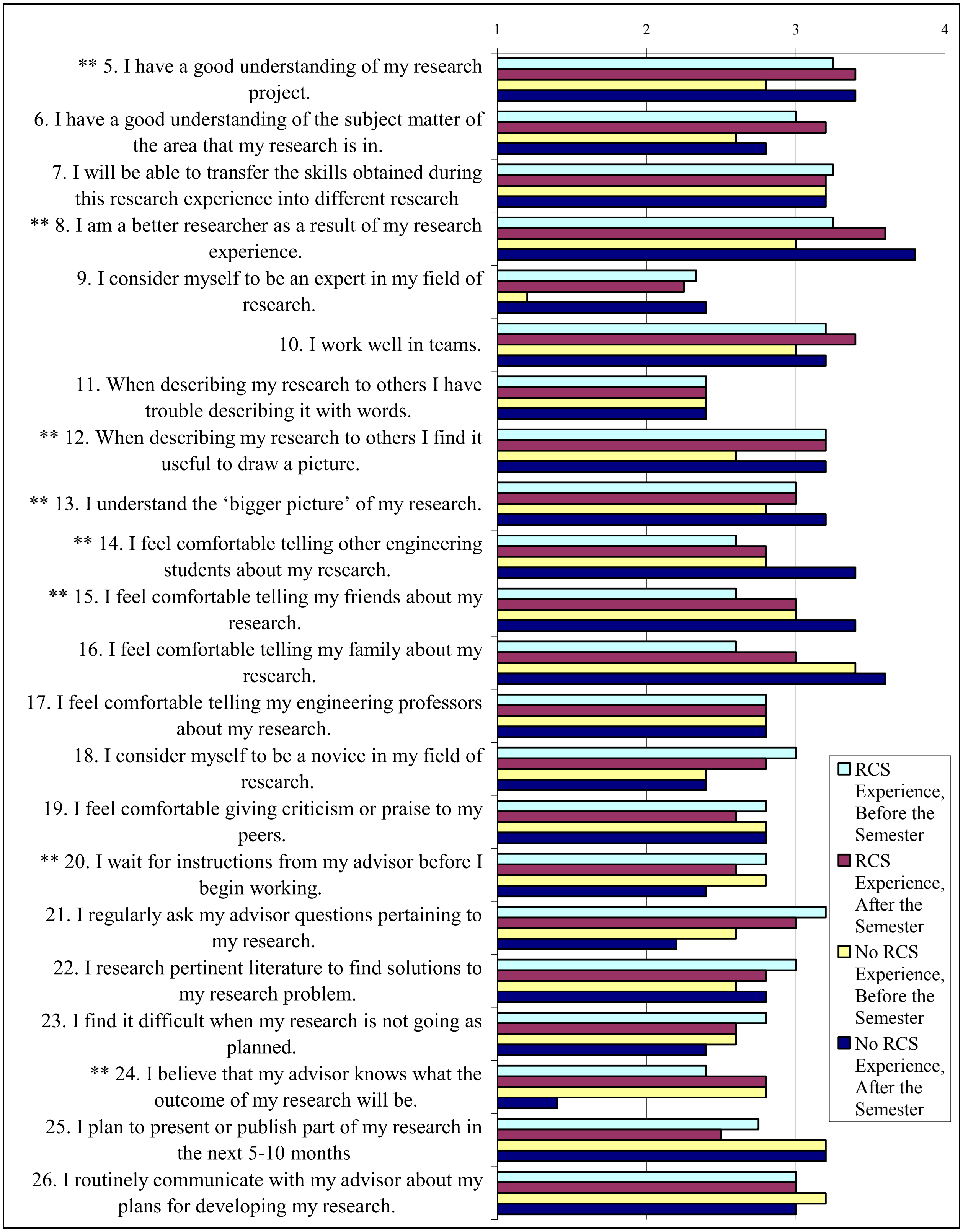

Figure 4--Results separated by students with RCS experience and those without RCS experience, ** denotes a statistically significant change in the student's responses without RCS experience before this semester, 1 -- "Strongly Disagree," 2 -- "Disagree," 3 -- "Agree," 4 -- "Strongly Agree"

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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 this survey indicate that the undergraduate students who had not previously participated in the RCS showed a measurable improvement in the areas of communication and metacognitive skills. 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.

Future Work

This research could be expanded on 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 to determine whether the students are becoming more complex systems thinkers throughout the RCS experience, 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

Complex systems study is laying the foundation for a revolution of all sciences to move beyond reductionism into holism.[3] This holistic approach involves not only looking at the technical aspects of a system, but the economic, social, cultural, global, and environmental aspects as well.

The complexities of the systems that we "engineer" are beginning to be understood because of the many breakthroughs in science. These complexities must be incorporated into engineering curriculum. Industry realizes the need for this change. Desmond Hudson, President of Northern Telcom Inc., said that, "My concern is for the students who come out of school suitably versed in mathematics, physics, and the sciences, but lacking an appreciation for literature, history, and philosophy. The view they have is that modern technology is a collection of components rather than an integral part of our society, our culture, our business environment."[4] There is a need for a change in the current engineering curriculum. 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.[5] The RCS engineering class is a start to developing a complex systems oriented method of educating our future engineers.

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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.

Dr. NANCY THOMPSON, Professor Emerita in the University of South Carolina English Department, is Co-PI and Director of the Research Communications Studio in the College of Engineering and Information Technology. With Dr. Rhonda Grego, she developed the Writing Studio Program, which provided an early prototype for the Research Communications Studio. She continues to pursue her academic research interests in applying cognitive and metacognitive learning theory to communications instruction. She participates actively in the education of graduate teaching assistants.

LORALEE DONATH is a Ph.D. candidate in linguistics at the University of South Carolina and a graduate assistant for the RCS. Her research interests span the sub-fields of discourse analysis, sociolinguistics, and linguistic anthropology.

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