Session 1355

Introducing Engineering Graduate Students to Learning Theory and Inquiry-Based Learning: A Collaborative, Interdisciplinary Approach

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Abstract

Newly emerging theories of how people learn have direct application in engineering. Constructivist learning theory, which holds that learners construct knowledge through active participation with others, is highly compatible with the hands-on, team centered, inquiry-based emphases of contemporary engineering education. Thus, gaining background in theory and practice of constructive learning uniquely prepares engineering graduate students who plan academic careers. This presentation describes a novel approach in which engineering graduate students learned about learning theory through study, discussion, and practice in a constructivist environment.

The approach was developed as a training program for engineering graduate students participating in the NSF-funded Research Communications Studio (RCS) Project at the University of South Carolina. These graduate students mentor small groups of engineering undergraduate researchers who meet in weekly Studio sessions to develop their research and communications abilities. The graduate student mentors also participate fully in the research project, working closely with other members of the project staff--two communications specialist co-PIs, two English graduate students, and engineering faculty research advisors--to study the ways that engineering students use language in learning to design and conduct research.

Training for the graduate student mentors includes a weekly seminar on key concepts of learning theory, discussion of ways that these theories explain the learning and progress of the undergraduate researchers, and development of theory-based teaching and coaching methods to be used in subsequent Studio sessions. In this presentation, the co-PIs and four graduate students describe their RCS participation and its role in furthering their understanding of how undergraduate engineering researchers learn through research. The graduate mentors also discuss what they have learned about their own research and professional development, and give recommendations for adapting the RCS graduate mentoring model for use at other institutions.

Introduction

New and heightened emphases on undergraduate research and student-centered, active learning in engineering require numerous changes to instructional approaches. One especially important area for change, and one that is likely to have significant impact, is in graduate education. To be prepared to teach engineering undergraduates of the future, today's engineering graduate students must learn how to mentor undergraduate researchers, how to design instruction based on new research on learning, and how to teach using inquiry-based learning methods. Currently, most teacher training efforts for engineering graduate students share an emphasis on traditional lecture courses that deliver information to students in a classroom or lab. Given the radical changes occurring in undergraduate engineering education, the future engineering professorate will benefit from learning how to support the learning processes of students in this new teaching/learning environment.

This paper describes a research-based approach in which engineering, English, and linguistics graduate students acquire understanding of current theories of learning as they mentor undergraduate researchers and interact with peers and professionals. The context of this interaction is the Research Communications Studio (RCS)[1], a unique NSF-funded project at the University of South Carolina (USC). The RCS uses a studio approach to integrate undergraduate research in engineering with research into the functions of language and communications in inquiry- or research-based learning. In contrast, traditional research groups led by an individual faculty member include post-doctoral researchers, MS and Ph.D. students, and, only if funds allow, undergraduates. Undergraduate pedagogical and mentoring aspects are highly variable, depending on the style of the PI. The amount and types of communication expected of undergraduates also varies widely. There is no interaction between groups. The RCS provides a structure for such interaction without interfering with the autonomy of a research project PI.

As shown in Figure 1, the RCS Studio includes three or four undergraduate students per group, one communications faculty, one communications graduate research assistant, and one engineering graduate student. The engineering faculty members have input through their research assignments to the undergraduate students. The engineering graduate students serve as mentors and provide technical guidance and support to the undergraduates as they gain increasing competence.

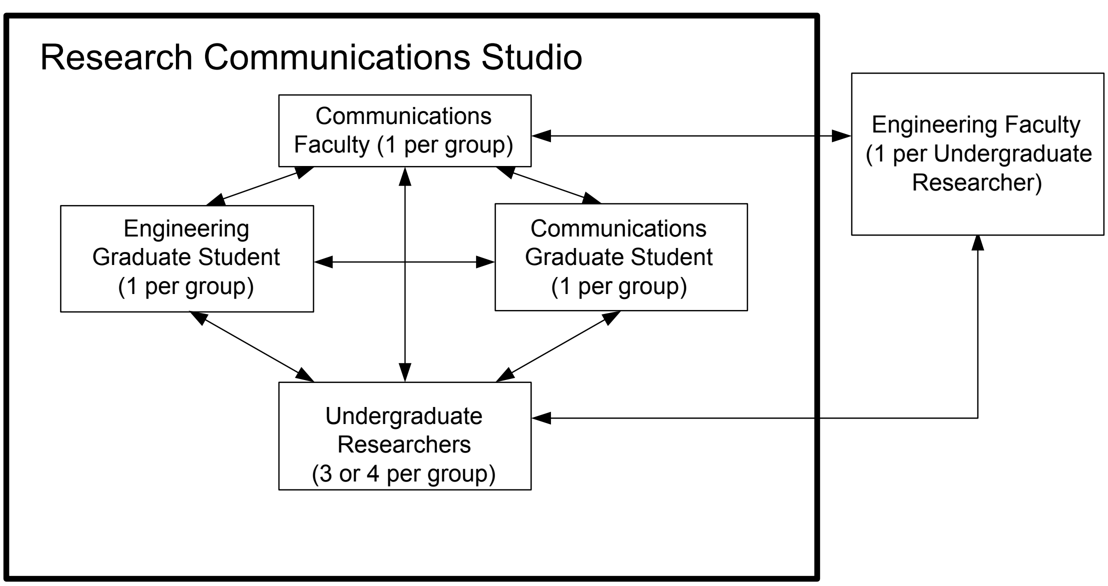


Figure 1: RCS Studio Organizational Chart

The experiences and learning processes of the mentors are the focus of this paper. Their observations and reflections that follow as case studies show how the mentors supported the cognitive development of undergraduates and applied principles of learning theory in their mentoring. Their collaborative writing of this paper was an integral part of their exposure to and reflection on constructivist learning theory. The comments of these graduate students demonstrate that the mentoring experience provided valuable insights for the future professorate. Through participating in, observing, and reflecting on the multiple levels of interaction in Studio sessions, the mentors develop metacognitive awareness of their own learning processes. They gain insight into how students learn through research and discourse.

Studio Teaching and Learning

The Research Communications Studio uses one of the principal teaching/learning methods found in engineering studio design courses: "hands-on learning" of a process such as design through frequent iterations and feedback from a more experienced mentor or coach. A number of institutions have also used studio approaches successfully in engineering introductory and content areas, such as physics [2, 3, 4]. The USC RCS is unique in that it engages novice researchers in communications about their work as they learn to report and present their research findings. In a process much like writing to learn, the continuing communications about research accomplishes a dual purpose. It provides an active and systematic learner-centered means of learning content and process, while at the same time it strengthens the learner's ability to communicate about research.

The RCS model establishes a link between undergraduate research and the engineering curriculum. Undergraduate research assistants who participate in the RCS project take one (1) semester hour of an independent study course in three (3) different semesters. The project thus accommodates the unique organization of research and independent study courses in each department, while providing structure for the various research experiences.

In Studio groups, three or four undergraduates meet weekly to discuss their research and learning with each other and with the RCS staff. The communications faculty supervise the RCS project, the English and linguistics graduate students serve both as research assistants in the project and as communications consultants to the undergraduates. The engineering graduate students, each of whom serves as a mentor to the undergraduates in a single RCS group, have the major responsibility of helping each of the undergraduates learn to think critically about their unique engineering research assignments.

For any graduate student contemplating an academic career, participating in the studio as a mentor provides an invaluable complement to traditional teacher training programs that focus on classroom instruction. The studio experience provides a unique opportunity to observe students' learning processes as they occur. In addition to observing learning in action, the graduate mentors participate in the undergraduates' learning processes by guiding and supporting students as they gain increasing competence. In this dual role of participant and observer, the graduate student mentors are themselves involved in inquiry-based learning about how people learn.

Theories of Learning

The research in this project is focused on the role of communications and all types of language (verbal, visual, symbolic, mathematical, etc.) in learning or cognitive development. The RCS project is guided by social constructionist, or Vygotskian, theories of learning. Table I below identifies the principal theoretical concepts being investigated in the project.

Table I. Social Constructionist (Vygotskian) Theories of Learning
Social Constructivism A philosophy of education that views knowledge as socially constructed and the tools of reading and writing as inherently social acts. Arising from works by Thomas Kuhn and Richard Rorty, social constructionism claims that knowledge is created, maintained, and furthered through the processes of conversation, collaboration, and consensus. Constructivist education seeks to teach students awareness of the underlying assumptions and expectations of a given discourse community in order to teach them how to communicate and interact within that community.
Zone of Proximal Development (ZPD) The zone of proximal development is the distance between the developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers [5].
Distributed Cognition A view that regards thinking not as an action that takes place wholly inside an individual's head, but rather as an activity that is distributed among the individual, other people, the physical environment, and the tools the person uses, including language and sub language structures as genres [6].
Guided Participation The effects of expert and peer guidance in facilitating learners' cognitive development in the educational setting [7].
Metacognition The process of reflecting on and directing one's own thinking and learning.
Peer and Near-Peer Tutoring The process of learning from and teaching people with the same or slightly different knowledge levels through one-on-one interaction, turn-by-turn dialogue, or small group discussion.

The Research Communications Studio emphasizes constructivist learning, cognitive development and metacognition. With its use of guided participation, and its involvement of peers and near peers as tutors, the RCS becomes a *distributed cognition* system for the participants, where multidisciplinary collaborative thinking about research-based learning and communications occurs. Using the studio model in parallel with students' research activities mainstreams students into the authentic, varied, and complex discourse of engineering research, as opposed to the hypothetical and simulated communications assignments included in the typical technical communications course.

Case Studies: Reflections of the Three Engineering Mentors and One English Graduate Student

As the four case studies included below reveal, the studio experience provided a perspective that is difficult to achieve in a seminar course on teaching or even through teaching a class under the supervision of a faculty mentor. Each of the three mentors focuses on what and how students learned rather than on the more traditional notions usually conjured up by the umbrella term of "teaching": preparation and delivery of content, class management, testing, assessment, etc. First, Eric Vilar's recognition of the importance of shared frame of reference brings to mind the Vygotskian concept of the zone of proximal development, the distance between what learners can do independently and what they can achieve with help. Second, John Brader argues that mentoring undergraduate researchers in a studio or constructivist learning environment is an ideal way for future faculty to observe how people learn and to learn how to facilitate their learning processes. Third, Sirena Hargrove-Leak illustrates the concept of guided participation through her description of how she works with the group to facilitate their participation in the research community. Finally, Beth Davidson, the English graduate student, connects the corporate concept of "collective expertise" with the distributed cognition work in the RCS.

Learning within the Zone of Proximal Development Though Peer and Near Peer Interaction – Eric Vilar

Eric Vilar, a first year graduate student in electrical engineering, is a graduate researcher in the Virtual Test Bed (VTB) [8], an international. multi-institutional modeling and simulation project based at USC. Prior to graduate school, Eric spent 1.5 years in undergraduate research. The RCS is his first experience as an educator, and while Eric does not have definite career plans yet, he is deeply interested in the teaching and learning process.

<u>Eric Vilar's Perspective</u>

> At the beginning of the RCS project, I mentored a three-person group, which included two electrical engineering students and one chemical engineering student. One outstanding undergraduate had advanced much further with his research than the other students. His progress in his field of molecular electronics was intimidating. Although no direct pressure was placed on me to be more knowledgeable than the undergraduate students, I still felt that as a graduate student I should have some idea of what each of the students in my group was working on. At least I could serve as an 'engineering interpreter' to the staff and other students

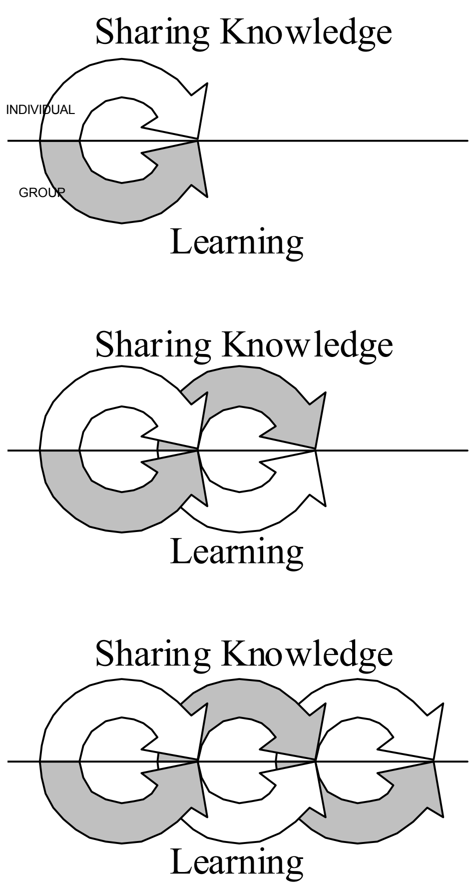
in my RCS group. However, when I asked this very advanced student to explain his research topic, he immersed me in the details of simulating the behavior of molecular devices. As I told him, I recognized that these details were contributions to his field of study, but they were unfamiliar and disconnected jargon to me. Obviously, direct communication between us was very frustrating at first, and I believe that this student gained more by taking part in Studio discussions of other students' research.

In our Studio group, communication with the advanced student was never easy because the rest of us had no frame of reference about his research in molecular electronics. However, as the group worked diligently to understand his subject, asking questions and listening to his answers, we established that his subject was about simulating the behavior of 'molecular units' that could someday replace transistors in a computer processor. Several weeks into the program, this student asked us to help him refine a poster summarizing his simulation results and demonstrating that the 'molecular units' could be used to function as logic devices. The student was concerned that his poster was "confusing." As he explained his graphics, he shared new essential information that clarified the basis of the theory he had used to develop his molecular device simulator. He then added a slide explaining that theory, which made the poster clear.

Another of my students, a sophomore, entered the RCS in a much different stage of progress; she was at the very start of her research project involving computer modeling of the methanol reformation process. She had little background in this newly acquired research subject, and as an independent researcher, she had only the faculty advisor and the RCS to support her learning. As a new researcher, she was unaware of fuel cell technology—an alternative energy source that requires a steady supply of hydrogen to produce electrical power. From my own research experience, I was somewhat familiar with this student's subject. I explained to her and others in the group that methanol reformers separate hydrogen from methanol fuel, and that they are a popular approach for avoiding the need to store compressed hydrogen. The student liked and adopted this perspective. Later, in introducing her project to others she noted that her research contributed to the development of alternative energy sources. In the same way that she learned from my earlier research, I later learned something from her research. As she explained that carbon dioxide is emitted during the process of extracting hydrogen from the methanol fuel, I realized for the first time that even though hydrogen fuel cells do not emit air pollution, extracting hydrogen from the hydrogen source could cause air pollution.

Establishing a shared perspective seems to be the key to communicating ideas successfully. For instance, to help establish a frame of reference with the sophomore student, our RCS group began sketching system-level flow charts that identified inputs and outputs to the reformer. This helped all of us understand the reformer's purpose. Later, the student mentioned that she needed information to model two types of reformers: one type of reformer that can be turned on and can quickly begin to output hydrogen and a second type that starts slowly but extracts more hydrogen from the fuel source. For the group discussion, I offered the analogy that the slow starting reformer would be good for a fuel economy car and that the fast starting reformer would be good for today's automobiles that start when you turn the ignition key. Inspired by this analogy, we sketched a system-level flow chart of a methanol-powered automobile. Then the group members began asking such questions as: "How is the reformer powered when the car is first turned on?" "What pollution is emitted by the reformer?" and "What is the chemical equation?" This group rather quickly developed a shared understanding of the research question. In contrast, establishing a shared frame of reference with the advanced student was more difficult. Eventually, as I gained understanding of what he had achieved thus far, I was able to help him move forward in clarifying his research for presentation to others.

After sharing my perspective with the rest of the research team, I was asked if I could illustrate the process of near-peer interaction, and my representation is shown in Figure 2 below. The white arrows represent the individual's progression in time, and the gray arrows represent the group's progression. The center line of the diagram represents a division between sharing and learning knowledge.



The individual (top) shares knowledge with the other group members to establish a frame of reference.

Having a reasonable understanding of the individual's topic, the group (top) provides guidance and instruction in order to help the individual progress.

With the group and the individual having advanced together, the individual (top) must now continue his/her research. At the next meeting, the individual and the group must reestablish or update the frame of reference to begin the process again.

Figure 2: Near-Peer Learning Diagram.

Constructivist Learning in the Studio – John Brader

John Brader is a Ph.D. candidate in mechanical engineering. As a graduate student he has guest lectured in four classes and was the full-time instructor for an introductory graduate level class. He currently acts as lead researcher in USC's Advanced Actuators Research Group (AARG) and supervises the AARG lab. Prior to returning to graduate school, John worked as an engineer in industrial research and development. He plans to pursue a faculty position balancing teaching with research.

John Brader's Perspective

The Research Communication Studio demonstrates the ability of students to both learn and teach within a less formal environment. This environment differs greatly from the traditional engineering classroom setting in which students receive most of their education. The primary difference stems from the openness of the Studio, which encourages students to actively participate in their learning. Further, students have a greater opportunity to learn from their peers. The combination of active learning and working with their peers and near peers exemplifies two primary educational theories: constructivism and near peer education. The RCS provides a proving ground for future faculty to hone their non-traditional teaching strategies as they apply constructivist learning theory.

The nature of the Studio allows for students new to academic research to proceed and develop their understanding at their own pace. Through this self development, students construct their individual knowledge and inherently become the owners of that knowledge. This feeling of ownership provides the foundation for the students to become experts within their research. As opposed to traditional classroom learning, during which students are "taught," constructivism allows students to add to their personal body of knowledge. This lends itself to significantly better understanding.

Constructivism is demonstrated continuously within the Studio. Students gain a deeper understanding of their own work because of the need to teach (explain) their research to others. Explaining their work to others often demonstrates a personal lack of understanding that must be corrected. Therefore, the process of constructing knowledge is allowed to continuously circle. For example, the student learns new information, then passes that information to others within the Studio. This is followed by questions from the others and ultimately leads to questions that require more research. This constructivist approach is integral to the other important learning mechanism demonstrated in the studio: near peer education.

Since the studio encourages communication among the participants, students spend a significant amount of time discussing their work with their peers. The peers provide feedback and discuss their own research. This interaction leads to further understanding of one's own research, the research of others, and the best practices for conveying the information associated with research. Simultaneously, the students work with near peers: graduate students. The graduate students typically represent more experienced researchers and communicators. Working with peers and near peers facilitates the learning process by removing barriers often associated with traditional education. The near peers can provide knowledge and experience, but do not intimidate students. Again, this promotes open communication and an improved learning environment.

Observations of these two theories at work in the Studio have already influenced how the mentors will approach instruction as future faculty members. Although many subjects do not lend themselves directly to a studio approach, opportunities for constructing self-knowledge and working with peers and near-peers can be integrated into nearly all traditional engineering subjects. For example, group work can be assigned to encourage students to learn from one another. Constructivism can be adapted for the classroom by allowing students to investigate laboratories or homework assignments without providing detailed instructions. Such approaches lead students to devise their own research strategies and construct their own understanding.

Overall, the studio provides a multifaceted program. It directly enhances the participants' ability to communicate, and it provides a forum for future faculty to practice improved teaching methodologies.

Guided Participation in the RCS Studio – Sirena Hargrove-Leak

Sirena Hargrove-Leak is a Ph.D. candidate in the final stages of her dissertation research in the Department of Chemical Engineering, where she supervises undergraduates assisting in her research project. She has conducted research as an undergraduate, Master's, and Ph.D. student and participated in several programs and workshops designed to prepare graduate students for academic careers, such as the African American Professors Program [9] at USC. Sirena ultimately plans to pursue an academic career and is vitally interested in approaches to learning.

Sirena Hargrove-Leak's Perspective

As one might expect, each RCS group varied slightly according to the initial cognitive levels and respective research areas of the student participants. The group that I worked with consisted of three chemical engineering students conducting research in related areas under the leadership of the same professor.

During the first Studio session, the students were asked to spend ten to fifteen minutes explaining their projects to the group as a means of introduction. At the close of the session, it was clear that the three students were at different levels in their development as researchers. Student A spoke with confidence and clarity when explaining his research project. Further, when asked for more elementary explanations of some of the technical concepts, he was able to give them with ease. In fact, he became so comfortable in his delivery that we had to ask him to stop in order to give the other students ample time to explain their work. Student B was much less articulate and self-confident. She did not seem to have a good understanding of her project. Because of her difficulty in gaining understanding, we used her allotted time to prompt her with a number of questions. Student C seemed to be at a level somewhere between the first two students in terms of his understanding and ability to articulate the importance of his project. While his explanation was generally informative and spoken with confidence, there were still some concepts he was not able to explain fully or clearly.

Over the course of the semester, I was able to observe both the gaps in understanding and in the students' relative cognitive development close rather quickly. I believe such improvements are attributed to the guided participation inherent in the RCS Studio experience. Throughout the semester, all of the student participants were given small assignments designed to sharpen their skills in communicating their work to varied audiences and to encourage them to think about their research more critically. The structured guidance of the assignments provided opportunities for the students to share their knowledge, but more importantly, incited them to organize and expand their knowledge in order to present their material professionally, confidently, and accurately. Student C stated it best: "RCS forces me to stay on top of my research. If I didn't perform research continuously, I wouldn't have anything to talk about at the meetings. Also, it forces me to have a better understanding of the material, so that I can convey the ideas better." Winsor [6] observed similar benefits of peers guiding one another in her exploration of distributed cognition with a group of interns working at a product development facility for a summer.

Peer guided participation also seemed to have a prominent role in fostering the students' individual development. In the Studio sessions that followed shortly after the initial meeting, it was clear that Students B and C worked very hard to close the gaps between themselves and Student A. They were more prepared and confident in explaining the goals of their work in subsequent meetings. Student B said, "RCS has helped me to clear up some of the details that I just kind of skimmed over when explaining the procedure of making a catalyst." We also noticed that by the end of the semester the students were actively engaging in conversations about their respective projects. Each expressed that they enjoyed learning more about each other's work and found that observing one another was useful for their own development.

The expert guidance of the RCS staff members and graduate students—through communication assignments such as web pages, class presentations, and poster presentations—has improved the students' technical communication skills. This is an important benefit because the chemical engineering curriculum at USC does not include such a course. It has also made RCS undergraduates aware of the importance of audience-appropriate writing. Most of the assignments required them to address an audience less knowledgeable than themselves, such as high school or freshman engineering students, which prompted them to develop a deeper, more detailed understanding of their work. Often a true measure of one's mastery of a topic is how well he or she can explain it to someone who has no prior knowledge of the topic. Therefore, I feel that this combination of expert communications instruction coupled with students' response to and guidance of one another's communications has sharpened the students' technical writing skills and their understanding of their work.

At the end of the semester, I was impressed by the tremendous growth and development of the students in such a short period of time. The gaps that once separated them had disappeared, and each student demonstrated the ability to communicate his or her work clearly, concisely, and confidently. I was also pleased with my own professional development. Participating in the RCS Studio project has exposed me to some very effective, non-traditional methods of teaching and learning that I definitely plan to use in my classroom one day.

Distributed Cognition in Industry and Education – Beth Davidson

Beth Davidson worked in the telecommunications industry, in companies like Lucent Technologies, which is now International Network Services (INS), and EMusic.com, where she also taught professional classes for clients and colleagues in the areas of telecom, routing and switching. Presently a first year M.A. student in Composition and Rhetoric, she plans to teach and research in this field, emphasizing the use of technology.

Beth Davidson's Perspective

The work in the RCS mirrors the processes used in industry, specifically the telecommunications industry. While working with computer, electrical, and mechanical engineers in a telecommunications environment, I participated in many sessions of distributed cognition; I just didn't know it at the time. As the INS website text below illustrates, the corporate world operates on the basis of distributed cognition.

> *We are the knowledge behind the network, and there are many ways to tap into our collective expertise. In addition to using that expertise on their engagements, our consulting engineers share their knowledge through articles, white papers, and books. Our web seminars tackle a different networking issue every two weeks, and give you an opportunity to ask questions directly to our engineers. We also conduct surveys to keep our fingers on the pulse of what's happening with the industry. And NetKnowledge keeps you up to date with networking news with our monthly newsletter delivered right to your inbox.*
>
> *INS KnowledgeNet is the industry's largest database of network solutions, enabling consultants to tap into* the collective knowledge *of fellow consultants and apply proven techniques to current problems.*
>
> *At INS, collaboration is a core value of the organization. Collaboration is practiced in every facet of our business, from the way we partner closely with our customers to deliver tailored solutions, to the dynamic nature by which we capture, develop, and transfer expertise to our consultants and throughout the company via our KnowledgeNet knowledge management platform. This collaborative culture results in satisfied customers whose business objectives are met through the most comprehensive technical and business solutions in the industry* [10].

The INS company's entire foundation was knowledge. We produced no physical products; we offered the client our knowledge, which was shared among employees worldwide. This company's operating premise is distributed cognition, the ability to learn from peers and near-peers, and to pass this knowledge to the client as well as use it to meet the client's needs. This procedure is similar to what students must learn when writing or researching a task for their professors.

The premise of the company is that the employee is never alone, whether solving a problem or creating a new design. This premise can be translated into distributed cognition in the workplace. How? Well, at the time it seemed like a "big brain" theory in that all the engineers and their knowledge were at my disposal. This shared cognition is vital in the field of telecommunications and network technology as everything moves so fast. There is no way one person could or should be expected to have all the knowledge. If an engineer is located at a customer site and experiences a network problem, he or she can instantly attach to a listserv and post a question. In my experience the consultant would receive a myriad of responses. Though it took some time to filter the information and understand its relevance to the problem at hand, the information was available. The knowledge of the whole came to enhance the knowledge of the one, and problems were solved. The customers were happy because their network was running, the company was happy because they would get paid and possibly acquire a new contract, the "collective" brain was happy to share knowledge, and individuals expanded their knowledge base. This type of operation brought intrinsic and extrinsic rewards to everyone involved.

Within the office, teams worked in a similar way. A problem was presented and a process similar to that of the Studio took place. A team may have consisted of a project manager, electrical engineer, and computer engineer, all with varying degrees of experience. Therefore, problems were examined from many different perspectives, leading to the best possible solution. Just as in the RCS, not everyone always agreed on the same path; team members would argue with pictures and words, but knowledge was always being passed among participants.

This type of development is essential for the networking industry to function. In the ever-changing world of technology, new "brains" must be added to the mix so no one's knowledge becomes stale. Peers and near-peers keep knowledge alive and growing. Without the ability to interact with others of similar and different backgrounds, there would be no new leaps forward in technology. The Internet and email may open up the lines of communication like nothing else before, at least in terms of speed and efficiency. However, without collaborative efforts and knowledge transfers that move with the same speed, technology would stagnate.

My experience was distributed cognition in action even if the term was not defined for industry.

Assessment

External assessment, an integral part of the NSF RCS project, is performed under subcontract with the Office of Program Evaluation (OPE) at USC's College of Education. OPE, as outside observers, are conducting surveys and interviews of students and faculty; scoring student writing; analyzing group processes from videotapes of sessions; and analyzing the effects of the RCS program on retention and recruitment of students. Internal evaluation conducted by the staff includes meetings with research advisors to determine their satisfaction with the program; development of a rubric for OPE's scoring of writing; thick descriptions (an ethnographic research term denoting extensive notes of social phenomena) of staff meetings and student sessions; and collection of demographic data. Assessment data from the first academic year ending May 2003 will be analyzed and used to guide any changes needed in the second year, as well as revisions to the assessment tools and procedures.

Though it is too early to assess the project at the time of this writing (the end of the first semester), interim reflections of the undergraduate students throughout the semester and end-of-semester evaluations have been positive. Three new students have joined the Studio project in the second semester and nine of the original ten are continuing.

Assessment of the mentors and graduate students' learning through the RCS experience is an ongoing process as part of the weekly staff meetings. In these meetings, mentors report on their sessions with students during the previous week and discuss any connections with learning theory that they observed. For instances, the first staff meeting of Spring 2003 was devoted to assessing what worked or did not work to provide a basis for planning the new semester's undergraduate small group meetings. For this planning meeting, one of the engineering faculty advisors joined the group discussion, thus augmenting the distributed cognition of the regular staff group. Based on this informal assessment, the staff decided to create a task plan for each of the undergraduates as the way to begin the new semester. The staff also reviews the small group learning process and makes suggestions for improving the process as necessary. In addition, following each Studio session, the mentor and the communications faculty review their observations. A long-term record of the sessions is kept in the form of detailed notes prepared by the English research assistants.

The task of writing this paper collaboratively was one of the important learning activities in graduate student education. Analogous to practices in more traditional graduate teacher education, this task was akin to a "final exam" in pulling together the learning that had occurred. By forcing articulation of learning, writing the paper was a means of bringing the staff's distributed cognition together and into focus, thus producing metacognition, or conscious knowledge of the learning. This collaborative writing activity, however, has an immense advantage over a final exam. Writing for publication is an authentic communication task for graduate students and faculty, in much the same way that working on funded research assignments is an authentic learning context for the undergraduate research students in the RCS.

Writing the paper provided authentic learning experience in the processes of collaborative authorship. As the writing progressed, the entire co-authors shared electronic copies showing tracked changes. As each collaborative writer read deletions and additions that co-authors made to their work, authentic writing instruction occurred. In this process, each writer could see how others expressed ideas and proposed clarifications to the emerging text. This process of collaboration also provided a sharp picture of how theory had been implemented throughout the semester. When the staff first met to discuss the paper, they lacked a shared overview of how theory and practice had been implemented in each of the three groups over the first semester of activity. However, bringing all the information together provided a means of "just-in-time" learning and theoretical interpretation of project results.

Summary and Recommendations for Adaptation Elsewhere

The value of the Research Communications Studio model is that it can be adapted into a variety of academic environments. It provides an authentic, active learning environment that engages undergraduate researchers with their research advisors, at the same time, graduate research students have an authentic situation for observing students' learning, providing a solid basis for teaching.

The RCS structure can be employed in almost any research university where undergraduate research exists. The first step in creating such a program is to seek support from faculty directors of funded research through nominating specific undergraduates for studio participation and providing a share of the studio's operating funds. The resources needed to establish a research communications studio include stipends for undergraduates and engineering graduate students, compensation for English and/or communications faculty and graduate students, office space and studio space, and computers, printers, and presentation equipment.

Current funded research at the institution should be the primary source of funds to operate the Research Communications Studio. This arrangement works to the benefit of PIs and undergraduate researchers alike to support the goal of integrating research and education. Under this arrangement, the students are guided by communications experts as they learn to communicate in an authentic research situation within the academic environment. If each faculty PI includes relatively small amounts within their research budgets to cover one or two undergraduates' participation in a studio program, the cost of a valuable instructional program would be shared by all. The cost to the PI's budget for each undergraduate's participation should be a pro rata share of the total studio budget for undergraduate stipends, communications faculty, operating expenses, and graduate student involvement.

Involving graduate students in the studio offers an ideal way to address two major concerns about the current quality of graduate education raised in the *Report of the Boyer Commission on Educating Undergraduates in the Research University* [11]. Declaring that "nowhere are the failures of graduate education more serious that in the skills of communication," the Report calls for a greater emphasis on communications within graduate education. The Boyer Commission also recommends that graduate students "be made aware of their classroom roles in promoting learning by inquiry." The Report explains that although some universities emphasize teaching techniques in their graduate education programs, "few have explored mentoring relationships or the synergy of these interactions (i.e., how do undergraduates teach graduates, and how do graduates stimulate the intellectual growth of faculty members?)(30-31)

The Research Communications Studio guides graduate students in mentoring undergraduates in communication, along with an orientation to theories of learning through inquiry and interaction. In the process of teaching undergraduates how to use communications throughout the research process, the graduate students have an opportunity to learn more about communications than is possible in either a traditional teacher training seminar or technical communications course. In giving feedback to undergraduate writers, the graduate students learn ways to critique their own writing. And through their collaborative writing with peers and near peers, the graduate students learn how to produce texts appropriate for audiences other than their own research directors and even how to give feedback and editorial advice to the communications faculty.

Through its effects at multiple levels within the academic research community, the Research Communications Studio is a model that can make major contributions to the quality of engineering education today and tomorrow.

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Dr. Nancy S. Thompson is an associate professor in the English Department at the University of South Carolina. With Dr. Rhonda Grego, she developed the Writing Studio Program, which provided an early prototype for the Research Communications Studio. She now spends half her time as Co-PI on the RCS project, where research on applying cognitive and metacognitive learning theory to communications instruction occupies her academic interest.

John S. Brader is a Ph.D. candidate in the Mechanical Engineering Department at the University of South Carolina. John returned to academia after several years in the research and development sector. Currently, he is the lead graduate researcher in the Advanced Actuators Research Group and is completing his doctoral work in piezoelectric piloted actuation systems. John plans to seek a faculty position upon completion of his doctoral studies.

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Sirena Hargrove-Leak is a Ph.D. Candidate in the Department of Chemical Engineering at the University of South Carolina who currently serves as a graduate engineering mentor for the RCS Studio. She received B.S. and M.S. degrees in Chemical Engineering from North Carolina Agricultural and Technical State University in 1996 and 1998, respectively. Her current research focuses on the heterogeneous catalytic synthesis of fine chemicals and pharmaceuticals, and she also has interest in membrane separations and membrane reactors. Sirena is nearing completion of her doctoral program and has a strong interest in pursuing an academic career.

Eric Vilar is a first year graduate student in the College of Electrical Engineering at the University of South Carolina. As an undergraduate, Eric spent 1.5 years involved with research. In addition to his studies, he is now involved with graduate research and he is participating as a graduate student mentor in the Research Communications Studio project.

Dr. Michael Matthews is a Professor in the Department of Chemical Engineering. His research is in the area of environmentally-friendly solvent technologies and he has published numerous papers in the area of supercritical carbon dioxide technology and ionic liquid solvent technology. His teaching experience includes several years of undergraduate chemical engineering laboratory instruction, which is a communications-intensive course. He and two other professors in the College of Engineering and Information Technology have worked extensively with Dr. Alford on the issue of communications skills and learning in the undergraduate engineering laboratory courses. His long-term goals include developing structure and standards for the growing of undergraduate research experiences in engineering while accommodating the constraints of funded research.