A Two-Step Program for Undergraduate Students to Gain Authentic Experience in the Research Process

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1. Introduction

The value of undergraduate participation in authentic research, especially in science, technology, engineering, and mathematics (STEM) disciplines, has been the subject of various studies over the past two decades. The Association of American Colleges and Universities (2008) identified it as one of ten high impact educational experiences. The Council on Undergraduate Research (2005) termed authentic research participation as “the pedagogy of the 21st century.” This is perhaps not surprising, as STEM students report both affective and cognitive gains from their undergraduate research experiences. Increased knowledge of how to conduct a research project, increased confidence in research skills, and an increased awareness of feeling or thinking like a scientist are often reported (Hunter et al., 2007; Russell et al., 2007; Lopatto, 2004; Seymour et al., 2004). Zydney et al. (2002) found that engineering graduates with undergraduate research experiences had self-reported “significantly greater enhancement of important cognitive and personal skills, including the ability to speak effectively, understand scientific findings, know literature of merit in the field, analyze literature clearly, and possess clear career goals.”

Summer experiences represent one of the most common approaches for immersing undergraduate students in authentic research. Yet, students are often not required to receive education, training, or other research-specific preparations prior to the summer. In other words, it is common practice to initiate the research experience at the onset of the summer program, which can limit the students’ research accomplishments and educational impacts. To address this issue, a two-step approach was developed and implemented in the spring and summer academic terms in the Department of Civil & Environmental Engineering at the University of South Carolina. This approach couples within-the-classroom and beyond-the-classroom research experiences. The first step requires students to complete a research course in the spring semester. The course culminates with the submission of a research proposal, which is the main deliverable and student assessment instrument for the course. The second step is for students to conduct research in the summer as outlined in the proposal.

2. Research Program

The two-step research program was implemented as part of a curriculum enhancement project in the Department of Civil & Environmental Engineering. The nanotechnology LINK project, or Learning Integration of New Knowledge, exposes undergraduate students to fundamental concepts and applications in nanotechnology, with an emphasis on end-of-life management of products containing nanomaterials. Content is delivered across multiple linked courses (Pierce and Berge, 2014) using active learning pedagogical strategies. To complement and extend student learning of nanotechnology, research opportunities were made available for a small cohort of students. The research program has three goals: (1) to create an integrated learning plan that connects curricular and extracurricular experiences in research; (2) to provide students with experiences across the entire research process; and (3) to broaden participation of underrepresented students in engineering.
This section describes the application and selection process, which was conducted during the fall 2014 semester for the first cohort. Detailed descriptions of the research course and summer research experience are provided in subsequent sections.

2.1 Chronological Description

In its entirety, the research program covers a 12-month period from September through August; Figure 1 illustrates the complete process. The program is advertised through the middle of the fall semester to all undergraduate students with declared majors in civil engineering. Applications are due in the first week of November, which coincides with the end of the academic advisement period. This schedule allows all interested students to discuss the program, along with the requirement to enroll in the research course, with their academic advisor prior to the application deadline. Finalists are interviewed within a few weeks after the deadline. Once the recipients are identified, all applicants are notified prior to the end of the fall semester, so that each student can make an appropriate decision regarding enrollment in the research course.

![Figure 1. Chronological Process of Research Program](image)

2.2 Selection Process

Eligibility requirements for the program were purposefully set to be inclusive, regardless of academic status or performance, with the intent of encouraging a diverse set of applications. Students were required to submit the following information: (1) academic transcript with anticipated graduation date; (2) description of prior research experiences; and (3) statement of interest that describes professional motivation for and anticipated personal gains from the research program. A total of 20 applications were received from a student population of about 300 undergraduate students. The applicant pool offered a representative sample of the total population, as illustrated in Figure 2. There was a reasonable distribution of GPAs in the pool, although the number of students with GPAs less than 3.00 was limited. It should be noted that most of the first-year and exchange students did not have an institutional GPA to report.

A maximum of six paid research positions were available through the nanotechnology LINK project. Nine students were identified as finalists, and six of them were selected for the program. However, one of the participants withdrew from the program prior to the summer research
experience. The final cohort of five students consisted of a first-year female, second-year male, junior female, senior female and senior male.

![Pie charts showing demographics of student applicants based on gender, GPA, and academic status.]

Figure 2. Demographics of Student Applicants based on Gender, GPA, and Academic Status

The research topics for each student were developed, in part, based on their current knowledge, skills, and specific interests within civil and environmental engineering. That process resulted in three research topics for five students, as follows:

- Transport of engineered nanomaterials in solid waste environments (two students)
- Generation of reactive oxygen species by TiO$_2$ particles in landfill leachate and as a result of discarded consumer products (one student)
- Design and manufacturing of nanomaterial-containing cement composites for nuclear waste storage (two students)

These topics were further developed and refined through the research process that each student experienced during the research course.

3. Step One - Research Course

3.1 Course Description

All five recipients completed a full-semester, three-credit course called *Introduction to Research in Civil & Environmental Engineering*. It is also noteworthy that three additional applicants chose to enroll in the research course, even though they were not selected for the program. This course fulfills one of the civil engineering electives that students must complete for the baccalaureate degree. The course itself is different from an independent learning or special research topics course; instead, it is taught in a traditional classroom setting but emphasizes interactive learning of the research process. Students learn how to select meaningful research topics and develop appropriate research questions based on the identification of knowledge gaps in the primary literature. To that end, students are required to meet with an assigned research mentor during the semester.
Even though the research course was created for undergraduate students, it was decided to cross-list the course, making it available for graduate students. The decision to cross-list this course created a more diversified student population and facilitated opportunities for undergraduate-graduate student interactions within the course. It was co-taught with two instructors, although guest instructors were invited to lead discussions on specific topics. All of the instructional tools were presented to students using active learning techniques. Creating an exclusively active and collaborative learning environment was considered to be critical in expediting acquisition of research skills. In other words, each class period was designed to facilitate hands-on and minds-on learning opportunities through peer-peer and peer-instructor interactions.

A significant number of communication-based activities were integrated throughout the course, including in-class and out-of-class written responses, in-class discussion pairs and discussion groups, poster presentations, oral presentations, and written summaries for reports or papers. Four disciplinary research and writing tools were particularly emphasized in this course: (1) research triangle; (2) literature map; (3) methods worksheet; and (4) one-page outline. These tools were presented chronologically in this order, and each one was intended to guide the students through the process of crafting a research idea and developing it into a well-written research document, such as a proposal, as illustrated with the Venn diagram in Figure 3.

![Diagram of research tools](image)

Figure 3. Disciplinary Research Tools to Develop a Research Proposal

The course itself is perhaps best described from a student perspective. As part of his E-Portfolio (see section 5), one of the students offered this description of the course:

“...As a whole the goal of the course was to teach students what research is and how to take a structured approach to conducting research. Part of the structure of research is the use of a tool called a “research triangle.” The function of the research triangle was to take a general topic and narrow it down to the key research question. It moves from what is known and proven, to that which is unknown and testable. A structured approach to a range of unstructured thoughts. In the class I started with the observation that “concrete containers used to store low level nuclear waste are allowing radionuclides to escape from the containers.” Here was a topic that offered many types of solutions and a whole host of opportunities to do research. By looking through existing literature to various solutions I could narrow down the larger topic to a specific question. The research question I ended at was “what type of mechanism, between functionalized MWCNT and cement particles, effect the mechanical and physical properties of cement?” This question narrowed down my topic to a challenging
question that could be traced back to the main topic in a logical manner. Additionally it was a testable question that was outlined with a structured method. The research triangle taught me how to move from the general to the specific. By removing unknowns through research, I was able to move down to a direct and effective question.”

3.2 Course Outcomes: Student Preparation for the Summer Research Experience

During the first week of the summer research program, the five recipients participated in a group interview with an external evaluator. The purpose was to discuss their perceptions of the research course and their proposed work plans for the summer. This section summarizes the student responses.

In describing the course, the first item mentioned was a process of defining the meaning of research, and, over several weeks, refining their definition. One student said,

As a class, we decided on what a 20-word definition of what research was the first day, and then at two other points throughout the semester, we came up with a new definition. At the end, we compared all three of them to see how our definition of research changed throughout the semester, based on what we studied.

The students said that their definition changed to reflect an understanding that the process is not linear, and that it includes a dimension of contributing to society. Research does not just answer questions; it also generates many more questions.

The course spent considerable time teaching the students to understand how to identify and gain access to relevant literature. Several students said that they had relied mostly on Google in the past, but that introductions to scientific databases and other academic services had taught them to use scholarly resources. The students reported that developing literature maps had been helpful in writing the introductions to their research proposals. Developing research questions was another significant feature of the course, both formulating the question and narrowing it to the point where it could be undertaken within the context of a summer research experience.

One aspect of research that students felt could have been covered better was their proposed methods. The students said that they had submitted their draft introductions twice for feedback, but did not have that opportunity with the experimental designs, which were submitted once with the final proposal. One student speculated that the lack of review was because most other students in the course were not planning to conduct their proposed research, in contrast to the summer research participants. To balance this, the students said they were receiving high levels of one-on-one assistance from their research mentors.

The students also remarked that the interaction between the two professors who co-taught the course was quite helpful. One of the instructors led most of the sessions, with the other adding thoughts and questions from time to time. Occasionally, the second professor would ask questions that the students had in mind, but had not articulated, and this was thought to be particularly useful.
The students were asked what they would like to accomplish by the end of the summer. Several said they were looking forward to the hands-on aspect of the experience, i.e., to be able to carry out their plans and see what will result. One talked about how the experience might change his perspective on working with unknowns:

Right now, I say, ‘this is so frustrating that I don’t know how to do this one thing that should be so simple,’ but I want to by the end of the summer to have achieved the mindset that, this is not—because this is an engineering mindset—being able to say, this is not insurmountable, it’s just something that is in your way right now.

One student reflected on how this experience might affect other aspects of life as well. The participant reflected that, in some ways, his background had prepared him to think about and advocate approaches to research questions, and to solving other kinds of questions:

There are decisions you have to make when you are selecting a method, so there are several different ways to conduct the test that [my research partner and I] are doing, and not all of them are wrong, and not all of them are right, so you end up picking a method and then you have to say, ‘all right, let’s defend why you did this, and explain why you did this’ in a way that helps somebody else understand. I have a background in sales, so a lot of times when a customer would come to me and say, ‘why did you pick this out?’ You have to learn to explain to them, ‘I picked this out because it’s the best fit for this situation. There were other solutions, but I felt that this was the best fit. To me, that’s what deciding on methods for research was. Figuring out the best fit.

Overall, the students felt the research course and the process of developing their research proposals prepared them well for the summer experience. However, the students felt less prepared to conduct specific laboratory procedures and methods. One said that the proposal was not as detailed as she was now realizing would be needed to complete her project; several others agreed that their big questions had to do with lab procedures, use of equipment, and similar practical concerns. The students also said they were confident that they would receive the support needed to work through those issues, however.

At this time, the students were not certain that their ideas had changed about graduate school. However, all agreed that they had developed new understanding about the ways that research is done, and how it might influence the practice of engineering.

4. Step Two - Summer Research Experience

Students were immersed in a 12-week research-intensive summer experience. The students were provided workspace within our departmental senior design room, which contains five partitioned workstations and a large conference table. The bulk of student time was dedicated to pursuing his/her research proposal, as each student worked on his/her project with their research advisor(s). In addition, there were a number of small group activities conducted throughout the summer.
The first week was for orientation to experimental research. It included an introduction to lab notebooks, lab safety training, and individualized equipment training, depending on each student’s specific project needs. Group meetings were normally held at the beginning of each subsequent week to (1) update students on specific research-related events (e.g., seminars and field trips) for that particular week, and (2) provide students with opportunities to share discoveries or ask questions regarding their research.

In terms of managing the research process, the most important elements of the summer program were the checkpoint presentations. At the conclusion of each four-week period, students were required to provide an oral presentation that included accomplishments and adjustments according to their proposed task schedule. These checkpoint presentations required students to review, reflect, and update their proposal and timeline. At the same time, these presentations were intended to serve as working drafts for the final presentation, which allowed the team of research advisors to make suggestions to improve presentation quality and public speaking. In addition, three of the students opted to present a group research poster (see Figure 4) at the USC Undergraduate Summer Research Symposium.

5. Graduation with Leadership Distinction

5.1 Program Description

The two-step research approach facilitates student participation in the USC Connect institutional program for Graduation with Leadership Distinction (GLD). USC Connect is a comprehensive learning initiative that supports undergraduate students with the integration of learning within and beyond the classroom. This initiative encourages students to connect formal learning with their own personal experiences through deep, reflective thinking. Students create a plan to guide how their experiences can be applied in a purposeful manner that impacts their long-term goals. The program walks students through a four-step process to choose, engage, reflect, and share what was learned with others as a means for documenting and demonstrating leadership skills.

Through USC Connect, students can earn special recognition for focusing on one of four experiential pathways: Community Service, Global Learning, Professional and Civic Engagement, or Research. Students who earn this distinction must demonstrate (1) extensive, purposeful engagement beyond the classroom; (2) understanding of course concepts in “real world” settings; and (3) application of learning to make decisions and solve problems. Students are recognized with graduation cords, and the distinction appears on transcripts and diplomas as Graduation with Leadership Distinction in [Pathway].

The requirements for earning GLD in Research are robust and entail the following:

1. **Extensive Beyond the Classroom Experience** – Students must participate in a research or discovery project for a minimum of two (2) semesters. Projects completed within a course may be used to fulfill the core experience requirement; however, core experiences may not be double counted toward fulfilling the coursework requirement, as explained below.

2. **Coursework** – Students must complete six (6) credit hours with a B or better from the approved course list for the Research pathway. Currently, approved courses in the
The Role of Engineered Nanomaterials in Waste Containment

Brittany Thornton, Grace Porter, and Elizabeth Sholar
Department of Civil and Environmental Engineering

Description: The NanoLINK summer research program investigates different research topics on nanotechnology in civil and environmental engineering. These projects are linked together by the involvement of engineered nanomaterials in waste containment systems. Our research explores a broad spectrum of the management of engineered nanomaterials in waste containment applications. These small materials can have a big impact on the surrounding environment.

Figure 4. Nanotechnology LINK Group Research Poster

Department of Civil & Environmental Engineering include *Introduction to Research in Civil & Environmental Engineering, Special Problems, and Independent Study/Research*. All three courses count as civil engineering electives for the baccalaureate degree program, which means that additional credit hours are not required to earn GLD in Research.
3. **Enhancement Experiences** – Students must participate in three (3) enhancement experiences that actively engage learning about a subject related to student research interests. Examples of appropriate enhancement experiences include field trips, conferences, workshops, special lectures and/or presentations, and official meetings. Enhancement experiences may not be double counted toward fulfilling the publication or presentation requirement, as explained below.

4. **Public Presentation** – Students must author a publication or complete a public presentation related to the Research pathway. Publications and presentations must be of a professional nature. Presentations must center on experiences within the Research pathway and include discussions of accomplishments, learning, and future plans. The Office of Undergraduate Research at USC provides two outlets for meeting this requirement: Caravel ([http://www.sc.edu/our/research_journal.shtml](http://www.sc.edu/our/research_journal.shtml)) for research publications, and Discovery Day ([http://www.sc.edu/our/discovery.shtml](http://www.sc.edu/our/discovery.shtml)) for oral and poster presentations.

5. **E-Portfolio** – Students must complete an E-Portfolio that demonstrates the significance and interrelationships of within and beyond the classroom experiences. The E-Portfolio must include sections on key insights, analysis, and leadership. USC Connect offers student support through one-on-one advisement, workshops, and an optional course designed specifically for completing the E-Portfolio. This course focuses primarily on helping students discern their insights, articulate how their experiences impacted their thinking, and consider how they can apply what they have learned to lead in the future.

5.2 **Integrating GLD in Research with Nanotechnology LINK**

The nanotechnology LINK project was designed to support the GLD in Research program. The summer research recipients were strongly encouraged, but not required, to pursue the distinction. Specifically, the two-step research program provided:

- one of the two required research experiences. Students were encouraged to continue their research projects in the fall or spring semesters following the summer program, as a means to earn the second qualified experience. In some cases, students had participated in at least one prior research experience, such that our program completes their research requirements.
- one of the two required courses, *Introduction to Research in Civil & Environmental Engineering*.
- one or more of the enhancement experiences. For the first cohort, two extensive field trips were organized in association with their research projects. One visit was arranged with the local Richland County municipal solid waste landfill, and the other visit was to the U.S. Department of Energy Savannah River Site, which included the Savannah River National Laboratory.
- the public presentation requirement. Each student was required to give a final project presentation to the entire research committee, which was comprised of the PI, co-PIs, and senior personnel on the grant. In addition, three students presented a research poster at an institutional showcase for undergraduate research, as shown in Figure 4.
- an online, electronic portfolio of their summer experience, using Google Sites, which the students could use as a steppingstone towards fulfilling the GLD E-Portfolio requirement.
5.3 Sample E-Portfolio

The impacts of the research program are expressed best from one of the participants. One of the five students from the first cohort, and co-author of this paper, earned Graduation with Leadership Distinction in Research in December 2015. He is the first student in our department to be recognized with this honor. In the fall semester after the summer research experience, he completed the optional course to develop his E-Portfolio. In it, he identifies four key insights, which are illustrated in Figure 5.

![Figure 5. Key Insights for Leadership in Research](image)

Within his E-Portfolio, this student opens with a description of each one of his key insights, which have been excerpted and shown below. These examples offer a concise illustration of the depth of thinking that the GLD program elicits, in this case, with regards to the research process. His complete E-Portfolio can be accessed online at washamer.wix.com/gldportfolio.

1. **Seek Guidance** – “This decision making skill is essential for making an informed and confident decision while also remaining accountable for the result of the decision.”

2. **Role in Society** – “This lesson is important because a modern complex society requires many parts such as infrastructure, health care, [and] education to function. As an individual it is impossible to run all of these parts alone, so finding your role within your work and living environment provides an avenue for making a significant impact.”

3. **Effective Question** – “An effective question attacks the root of a problem, ignoring the symptoms of the problem. It takes the most direct path to arriving at an appropriate answer.”

4. **Managing Expectations** – “By managing expectations I clarify what I am capable of to whoever I am working with. This provides me the space to get the task done the right way without overloading myself but also maintaining efficiency.”
6. Summary

This paper reviews the first implementation of a two-step approach for undergraduate student immersion in the research process. The research program was initiated in the context of a curriculum enhancement project to expand student learning of nanotechnology in civil and environmental engineering applications. Three female and two male students, ranging from first-year to senior, were selected to participate in the program. The two-step approach is based on the principles of integrative learning, where students make connections between within-the-classroom and beyond-the-classroom experiences. Here, students first learn how to develop a research proposal within a designated research course, and then endeavor to accomplish the proposed work as part of a paid summer research internship. Qualitative evidence of its impact was acquired, in part, through student interviews and a published e-portfolio of self-reflections from one participant. That evidence suggests that the research course contributed to deeper learning and a more meaningful summer research experience.

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