# ERSP: A Structured CS Research Program for Early-College Students

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## ABSTRACT

Research experiences for undergraduates (REUs) have many positive outcomes on students' perception of and retention in Computer Science (CS). Yet nearly all REUs are aimed at late-college students, well into a CS program. We present the Early Research Scholars Program (ERSP), a 4 quarter program designed to engage early-college (first or second year) CS students in high-quality research experiences in active research groups at a large research university. ERSP's *structured course-supported group-apprentice model* and its unique *dual advising structure* make it possible to vastly increase number of early-career CS students who participate in high-quality research experiences with little additional burden on individual faculty mentors. ERSP's focus on *community building and support* makes it particularly appropriate for students from groups who are traditionally underrepresented in CS. This paper reports the structure of the program and observations and learning thus-far with ERSP, with the goal of enabling others to implement this program at other large research-focused universities.

## CCS Concepts

•**Social and professional topics** → **Model curricula;** *Computer science education;*

## Keywords

diversity; undergraduate research

## 1. INTRODUCTION

Research experiences for undergraduates (REUs) have been shown to increase retention for students in computer science, particularly for women and underrepresented minorities (URMs) [7, 6]. Unfortunately, at many large schools research experiences are usually ad hoc. Undergraduates must seek out individual research positions, and they usually can only get these positions late in their undergraduate careers. Most REUs are not appropriate for high-potential students early in the major because REUs usually assume at least some advanced CS knowledge. Additionally, most faculty do not have the resources for the "hand-holding" needed to take on early-college students.

We developed the Early Research Scholars Program (ERSP) with the goal of providing a structured research experience for first and second-year CS students that would impose a minimal additional burden on the faculty supervising the research. ERSP is a 4-quarter[1] program in which students learn fundamentals of CS research in a classroom setting, and apply this knowledge to a group-based research project within an active research group in the department.

The central components of ERSP are:

1. A **course-supported apprentice model** in which students work on real research problems within an active research group as they learn the fundamentals of CS research in a structured class setting.
2. A **dual mentoring framework** in which students are co-advised by a central team of ERSP mentors and a faculty or grad student research mentor.
3. A **team-based structure** that builds community and student-to-student support.

Although ERSP is likely appropriate for all early-college CS students, we designed it explicitly as a retention program for women and URMs in CS. We found that these students were leaving the major at disproportionately high rates compared to White and Asian men, particularly in the second year of the major. Our hypothesis is that by exposing students to research—with all of its struggles, applications of classroom knowledge, and community—students would feel more connected to the department, have a better idea of the applications they were learning in their classes, and be more willing to persist when they struggled in their classes.

ERSP has been running for almost two years. Its novel structure has allowed us to increase the participation of first and second year CS students in research from just a couple per year to up to 36 students per year, so far. Almost all ERSP participants have been women or URMs and the majority of participants have completed or are on track to complete all four quarters of the program.

Although the program is still new, our initial results have been so positive that we are eager to share it with others. This paper describes ERSP's novel structure and components with the goal of allowing others to replicate our successes. We conclude with some early results from cohort 1 and some future directions for this program.

[1]Our university uses a quarter-system in which there are three quarters (fall, winter, spring) in an academic year



*ITiCSE '16, July 09 - 13, 2016, Arequipa, Peru*



ISBN 978-1-4503-4231-5/16/07...$15.00

DOI: http://dx.doi.org/10.1145/2899415.2899436

## 2. BACKGROUND AND RELATED WORK

REU programs exist at many levels, from nationally coordinated programs (e.g. the NSF REUs), to programs on individual campuses. REUs are widely acknowledged to have many positive benefits for students including increased confidence, increased interest and retention in STEM, and increased likelihood of pursuing graduate study [15, 1, 16].

Evidence also suggests that structured research increases STEM program retention of URMs [10]. Women and URMs face particular challenges early in a college CS career due to feelings of isolation due to a poor cultural fit compounded with an initial lack of experience. This creates an exclusionary feeling for students and a negatively skewed view on the nature of CS. [2, 13, 5, 11, 12]. A structured research experience can help students develop their "science identity" [4] whereby a student displays competence and performance in science that is affirmed by others, and this recognition is acknowledged by both the individual and their peers.

Several existing research programs share our goal of attracting and retaining women and URMs in STEM. Large multi-institutional programs like the Louis Stokes Alliances for Minority Participation (LSAMP) Program at the University of Maryland [8] incorporate research experiences in addition to broader community-building activities and support mechanisms which have been proven effective in retaining minorities in STEM fields. While extremely effective, these programs are also expensive to set up and run successfully.

ERSP is more directly comparable with institutional programs such as the UR STEM program at the University of Northern Kentucky. UR STEM engages students from rising sophomores to rising seniors in research projects across the STEM disciplines, with an emphasis on targeting students at risk for leaving the major at the lower end of the academic spectrum [3]. The major difference between that program and ours is while UR STEM focuses broadly on STEM, ERSP focuses strictly on early-career CS students. This focus on CS is important because the challenges faced by students engaged in CS research may be greater than in other disciplines. Barker finds that when CS students have less experience or are not well-prepared for research, some faculty mentors attribute their struggles to their gender and/or their race [1]. ERSP's focus on CS allows it to address these issues directly within its mentoring structure.

ERSP takes some of its inspiration from the Affinity Research Group (ARG) model [17], which incorporates the deliberate design of research groups, student apprenticeship structure and aspects of broader community building. While the ARG model is rich, it requires that individual faculty mentors have a a deep understanding of and strict commitment to the model. In a large-scale setting, this overhead can make it difficult to implement. In contrast ERSP's dual-mentoring model eases this burden on the research mentors by centralizing the support and community building mentorship to a central ERSP mentoring team.

## 3. PROGRAM OVERVIEW

We aimed to create a program that would be able to sustain the involvement of a large number of first and second-year CS students in a productive, positive CS research experience without imposing undue work on individual research advisers. This program needed to have sufficient structure and support for the students to build their skills, confidence and feeling of belonging in CS while keeping the administrative overhead low. To achieve these goals, ERSP is a dual-mentored, team-based program where students are supported and trained by a central mentoring team but also complete a research project under the direct supervision of a faculty member with an active research group.

Each ERSP cohort begins in the spring quarter and runs through the following academic year (Figure 1). Upon entry to the program, students are grouped into ERSP teams of four and then matched with a research group. In the first quarter (spring), ERSP students receive research training through a 2-unit academic course, while attending their research group's meetings or seminars to begin to acclimate themselves to the context of research. In the fall, they continue their training with a second 2-unit academic course, but also begin to transition to freeform research by meeting weekly with their research adviser to propose a project to complete in the winter and spring. In the winter and spring they complete their research project under the dual supervision of the ERSP mentor and their research mentor. Finally, students conclude their ERSP experience with a poster presentation at a department-wide undergraduate research poster session at the end of the academic year.

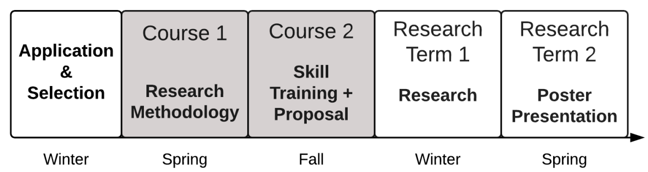


**Figure 1: ERSP general timeline. See Table 1 for a detailed timeline of the highlighted course blocks**

We developed ERSP to match our quarter-based academic year, but we discuss in Section 9 how this timeline, including the coursework, can be adapted to a semester-based year.

## 4. COURSEWORK+APPRENTICESHIP

A lack of consensus prevails on the nature of Computing Research Method [9]. As noted by [9], research training is often done via apprenticeship, with little formal structure. However, that same report argues that there are specific skills and knowledge that can be formally taught via structured coursework. ERSP combines the benefits of a formal course with an apprenticeship via a 2-phase training+application structure. In the training phase, students take a course in which they learn necessary skills and knowledge in the context of an apprenticeship experience with a research group. In the application phase, the coursework is phased out in favor of freeform research.

### 4.1 ERSP Support Courses

During the training phase of the program (spring 1 and fall) ERSP participants take a research methodology and skills course that is grounded in the context of the research lab they will be working with. The rough content and timeline for these courses are given in Table 1.

The first course centers on developing a research mindset, focusing on a range of skills from communication and teamwork to familiarity with the research cycle. At the end of this course, students orally present an overview of their lab's work and the related literature, along with an initial proposal for how they might contribute to this work.

| | ERSP Quarter 1: Course 1 topics |
|---|---|
| 1 | Effective group work |
| 2 | Research problem identification and refinement |
| 3 | Reading CS research papers |
| 4 | Effective literature search methods |
| 5 | Independent learning methods |
| 6 | Effective technical oral communication |
| 7 | Grad student life |
| 8 | **Final Presentation: Oral** Research Problem Overview |
| | **ERSP Quarter 2: Course 2 topics** |
| 1 | Research proposal writing |
| 2 | General CS research method |
| 3 | Experimental design |
| 4 | Interpreting results |
| 5 | Analysis and visualization of data |
| 6 | Research ethics & opportunities beyond ERSP |
| 7 | Research project management |
| 8 | **Final Presentation: Written** Written Project Proposal |

**Table 1: ERSP course topics. We schedule 8 of 10 weeks to accommodate holiday and reflection time. See: https://sites.google.com/a/eng.ucsd.edu/ersp-course-2015-2016/ for more details and updates**

The second course focuses more on specific skills required for success in a research group. First and second year students generally have limited or no experience with statistics, data analysis and the programming languages that support these. In this second course we teach students just enough to understand the importance of these skills, guide them in applying these basic skills to problems specific to their research group and lay the groundwork for further developing these skills outside of the course. The second course also revolves around its final deliverable: the written project proposal. Students produce and refine several drafts of this proposal until at the end of the quarter they have a document that details the research they will carry out in the last two quarters of the program.

The novel aspect of these courses is that every activity is grounded in the student's specific research area, thus the courses begin to bridge the gap from structured assignments to open research practice. For example, when students learn to read a research paper in class, each group of students reads a different paper which is directly related to their own research group's work.

## 4.2 Research Apprenticeship

The ERSP research apprenticeship begins even in the training phase of ERSP. During this training phase in addition to attending class, students attend their research group's weekly meetings. They are not expected to participate in these meetings, but rather simply to observe to get used to the structure and culture of their research group and of research in general. During the second quarter, the coursework gradually gives way to focusing more on the group's research proposals, preparing students for independent work in the second phase of the program.

The second half of ERSP, the application phase, focuses on applying all of the skills taught in the first half in a real-world research scenario. During this phase students work in their ERSP groups to complete their proposed research under the dual mentoring of the ERSP staff and their research advisor. This unique dual-mentoring model is discussed in more detail in the next section.

The work in this phase is highly dependent on the specific research project, but some common requirements are shared across all participants. Students maintain weekly online logs in which they record their goals, activities, questions, and results. These logs not only provide a record for the student's own use, but are also open for the group members and lab mentors to see. In this way all knowledge and concerns are openly discussed and fosters a sense of teamwork and collaboration. Students also produce two concrete deliverables at the end of this phase: a poster presentation at a department-wide undergraduate research poster session, and a written report that details their problem, approach, results, and information on the state of the project that would allow another student to quickly get up to speed to continue their work.

# 5. DUAL MENTORING STRUCTURE

ERSP employs a dual-mentoring structure that provides the high-touch guidance early-career students require without undue burden on technical research faculty. ERSP students have two research mentors (or mentoring teams): a lab mentor from the assigned research group and an ERSP mentor who oversees all the research groups. The lab mentor is a graduate student or faculty member (or combination) from the assigned research lab; there is one lab mentor for each ERSP team. In contrast the ERSP mentorship team comprises a single lead faculty member (the ERSP course instructor and program director) and an advanced graduate student with experience in leadership, research, and a variety of CS areas. The ERSP mentor[2] focuses on general research and personal guidance, leaving the lab mentors free to provide technical mentorship, more similar to the interactions they would have with graduate students.

The time costs for a fully scaled ERSP program are:

- ERSP graduate student mentor: 10-15 hours per week.
- ERSP faculty mentor: 1 full time or 2 half-courses per year plus 6-8 hours per week in non-course quarters.
- Lab mentors: 0.5-1 hour per week.

## 5.1 ERSP Mentor

The role of the ERSP mentor is to bridge the gap between the predictable and well-defined nature of classroom projects and the fluid and open-ended nature of academic research. The responsibilities of the ERSP mentor include: helping groups set personal and research goals, assisting with time management and communication issues, addressing research issues, and providing emotional support and encouragement.

During the application phase of ERSP (winter and spring), the ERSP mentor meets weekly with each group. During these meetings the mentor may address personnel or com-

[2]We will use the singular term "ERSP mentor" to refer to the ERSP mentoring team.

munication issues, set weekly goals, help students formulate technical questions to ask their lab mentors, provide general computer science or tool support, provide general support or coaching, or some combination of these. In short, ERSP mentors try to take on as much of the mentoring duties as they can, stopping only when they lack specific technical knowledge required for a particular project.

The workload of the ERSP mentor is significant, requiring 1-2 hours per ERSP group per week. While it is possible for a single faculty member, or even an advanced graduate student, to serve as ERSP mentor, we have found that this position works best when it is split between a faculty member who provides very high-level guidance and an advanced graduate student who provides the majority of the lower-level mentoring support. While faculty tend to have more management experience, graduate students are more deeply engaged in the department's culture and are closer in age and experience to the ERSP participants. However, this graduate student must be chosen carefully. Ideally he or she is an advanced PhD candidate with a broad research background and mentorship experience.

## 5.2 Lab Mentor

The role of lab mentor is to provide expertly informed research direction to the students and to provide a research environment into which ERSP students can be immersed.

During the fall, winter and spring lab mentors meet weekly with their ERSP group. In the fall in consultation with the ERSP mentor, lab mentors help ERSP groups identify and refine their research project. They also provide the computational resources and tools needed to work on these projects. Lab mentors are expected to include their ERSP students in lab-wide events as much as possible.

Only occasional coordination between the ERSP mentor and lab mentors is required; we recommend quarterly synchronization either in person or over email, except in extraordinary circumstances such as long standing lack of progress in student groups.

Many faculty are suitable lab mentors, provided they meet the following criteria. First, mentors must have an active research group and weekly lab or student meetings that they are willing to let ERSP students observe. Second, mentors must be willing to devote a minimum of 30-minutes per week to meeting with their ERSP group in addition to providing their group offline channels such as email or a discussion board to get their technical questions answered. Finally, we require that mentors express an interest in the program's goals of engaging more early-college students, women and URMs in particular, in computer science research. We find that mentors who embrace ERSP's goals are more likely to provide a working environment that emphasizes building students' research experience and students' self-perception as scientists rather than scientific results.

We find that when faculty lab mentors engage or delegate to their graduate students it often produces the most productive lab mentor relationship. Graduate students tend to be more closely involved in the technical details that will trip up ERSP students, and ERSP students can more easily relate to a student who is just a few years ahead of them in their careers than they can to a faculty member, no matter how well-intentioned.

# 6. RESEARCH PROJECTS

The selection of an appropriate research project is one of the most difficult, yet most critical, aspects of ERSP. The projects must be real enough that students feel they are making a real contribution, but not so critical that they will derail a lab's progress if unsuccessful. Every lab is different but we identify several key properties the projects must possess to be suitable for ERSP.

1. **Low Research Risk:** The lab mentors should be familiar enough with the research involved in the project that they know what outcomes to expect. Optimization projects or repeated experiments are examples that fit this criteria.
2. **Clearly Defined Milestones:** The project should be composed of sequential steps that are defined before the investigation starts.
3. **Accessible Topic:** The project should not rely heavily on specialized CS knowledge. If it is required, students must have either demonstrated knowledge in the area ahead of project assignment or else be trained in the domain specific prerequisites by their lab ahead of the main investigation.

In terms of scope, a general rule of thumb is that the ERSP group research project should be broadly equivalent to a lab orientation research project that a PI would assign to a first year PhD or as a one-semester Master's thesis project.

We illustrate an application of our project criteria with a successful ERSP project from cohort 1.

**Project context:** The structure from motion (SFM) algorithm allows archaeologists studying remote or hard to reach areas to construct 3D models from 2D surveillance images. However, the algorithm cannot yet be performed in real-time. The Embedded Systems group at UCSD is working to optimize SFM towards real time performance.

**Specific ERSP Project:** The ERSP project involved profiling an existing implementation of SFM on a particular hardware platform. The group then experimented with replacing high-level instructions with machine-level instructions specific to the hardware platform, and measured the speedup obtained.

**Project Suitability Discussion:** This example project was suitable for ERSP for the following reasons:

1. **Low Research Risk:** The SFM algorithm was well known in the literature and had been explored by the Embedded Systems research group previously. Students were given a SFM implementation built from commonly used open source libraries. As such, the students had a ready-made research environment, working example of the research problem and community support on their research tools.
2. **Clearly Defined Milestones:** At a high level, project milestones were software profiling, software optimization and software validation. These milestones could be worked on sequentially.
3. **Accessible Topic:** SFM is a complex algorithm, and hardware-level optimization required the students to acquire domain specific knowledge. With guidance from the Embedded lab graduate student who met with the students and coordinated with the ERSP mentor, students were able to map what they were learning in the computer organization and systems programming course they were taking to the knowledge and skills they needed for their project.

**Group Results:** Although this ERSP group experienced above average attrition throughout the program, the research project was completed successfully. The baseline SFM implementation was accelerated 50%. Additionally, one team member continued researching with the Embedded lab after the end of the ERSP program.

# 7. STUDENT SELECTION AND GROUPING

ERSP targets high-performing students early in their CS careers. Because of the fluidity of student standing at UCSD, we use time in the major instead of their freshman or sophomore standing. Students who apply to the program must not yet have completed any upper division courses in the major at the time of application.

Students are selected based on academic performance, interest in CS research and the ERSP program, and potential contribution to diversity in CS. The application consists of their grades in CS courses they have taken so far and their answers three questions that elicit answers related to the criteria on which they will be judged. More details of the application can be found on the ERSP website[3].

A committee of faculty and grad students numerically rate each applicant on their academic potential, their specific interest in the ERSP and their potential to contribute to the diversity of the CS major. Based on the results of these reviews, a threshold is determined above which an applicant is deemed "worthy of selection." The details of how this threshold is determined are beyond the scope of this paper. This threshold produces a set that is larger than the number of students that the program can accommodate, and from this set the participants are randomly selected.

This process of thresholding and random selection was chosen for two reasons. First, because the applicants are so early in their careers it is difficult to make fine distinctions between applicants. Second, this process gives us a built-in control group to which we can compare in our evaluation.

We are currently still ramping up to the target size of the program: 40 students matched with 10 research groups, our target for cohort 3. Our first two cohorts have comprised 23 students with 6 research groups, and 36 students with 9 research groups, respectively.

ERSP group formation and research group assignment is done based on a combination of students' expressed interests and, most importantly, scheduling concerns. During the application process students are asked to rate their interest in a number of sub-fields of CS. After they are selected, they are polled about whether they would be free to attend the group meeting times for each of the research groups involved in ERSP. We then manually match students by assigning students who are free to meet at a group's meeting time, attempting to take into account students' research interests.

# 8. INITIAL OUTCOMES

It is too early to assess the long-term retention impacts of ERSP on its participants, but initial results and student feedback have been encouraging. Cohort 1 engaged 23 students (18 women, 6 URMs) and cohort 2 engaged 36 students (29 women, 6 URMs), all in their first or second year of the CS major when the program began. 17 of the cohort 1 students finished the 4-quarter program, while 28 of the cohort 2 students are still in the program.

[3]https://sites.google.com/a/eng.ucsd.edu/cse-ersp/

Students' qualitative feedback after completion of the program gathered through focus groups and interviews illustrate some of ERSP's strengths and areas for improvement. Because the focus of this paper is the program itself and the evaluation of the program is still in its early stages, we present only a few piece of feedback from cohort 1, and save a more complete discussion of these results, and further statistical analysis, for future work.

Students completing the program left with a greater appreciation for the diversity of research available with the CSE community and how different fields connect.

**Student A:** *I was working on a computer vision thing and you could apply that – I want to do machine learning or artificial intelligence in the future – you can connect the two... Yes, I could bridge them. My mentor knows that I'm interested in AI so what he's trying to help me to do now is find aspects of the project that I could apply machine learning to so I could still work on this project and have experience in machine learning.* [14]

We also find evidence that ERSP contributes to developing students' science identity. While said in different ways, students reported being more confident, less intimidated, and leaving the program with a sense of accomplishment.

**Student B:** *Like I said before, a sense of accomplishment I think. Just saying oh, we did this whole year's worth of program. We stuck to it; we got our work done. We just did the piece by piece, all the work that we needed to do to be able to present at that conference... So that's something that I think is really cool.*[14]

Of course, not all feedback was positive, and student feedback helps us shape future changes to the program, discussed in the next section. Most suggestions for improvement centered on an earlier introduction to research, and to some extent a compression of the coursework associated with ERSP.

# 9. DISCUSSION AND FUTURE WORK

We hope that our experience inspires others to implement ERSP at other large universities. Here we include a discussion of the most challenging aspects of running ERSP to help others avoid potential pitfalls in implementing the program.

**Student Motivation** The long length and fluid requirements of ERSP in comparison to typical CS courses means extra effort must be made to keep students motivated and focused on the program each quarter. Students are likely to prioritize specific course assignments and course grades over self-driven research, especially when they feel like they are not making progress in their research. Our approach to keeping students engaged and motivated is to frame activities in a 'big picture' that spans the entire duration while emphasizing support that will be provided to them in helping them reach their next milestone. Additionally, we emphasize the positive differentiation factor that ERSP provides their resume over their coursework.

**Student Support** The scale of ERSP requires support from multiple professors and labs. While we have not had trouble recruiting lab mentors, we note a occasional significant disparity in student support from lab mentors. In the typical case, the dual mentor framework can compensate with ad-hoc support. In the worst case, groups may have to re-deploy to another lab, which requires careful management to maintain student morale.

**Scheduling Logistics** The large size of the program creates difficulty for scheduling meetings with all student group members. These time conflicts can make management of teams a difficult task. We have three strategies for combating this problem. First, we use student schedule as a factor in selecting groups, matching students with the most compatible schedules. Second, we insist students determine contact hours as a priority when scheduling their other commitments at the start of each quarter. Finally, we plan to shorten ERSP to three quarters to reduce the frequency of schedule changes, as discussed below.

As ERSP enters its third cohort, we continue to revise the program. The most significant planned revision for cohort 3 involves shortening the program's duration from 4-quarters to a single academic year. Based on student and mentor feedback, and our own experience, the first quarter does not seem to provide a gain that is worth the added work. Although many students appreciate this first (spring) quarter as a time to slowly acclimate to research and their research group, others find the start of the program frustratingly slow. Additionally, students forget most of what they learned in the spring over the summer, and the transition between spring and fall provides an additional challenge of keeping groups together in their research group meetings in the face of completely new academic schedules. Beginning in 2016, students will apply and be accepted to the program in the spring quarter, but will not begin until the fall quarter. We will keep the application and acceptance in spring rather than summer to combat the potential attrition that can start to occur over the summer after students' first year.

The transition from 4-quarters to a single academic year will also make it clearer how this program can be adapted to a semester-based academic calendar. We will condense the ERSP support course into a single quarter carrying 4 units instead of 2 so that students can devote more time to research training and project proposal development. However, in a semester-based calendar, our two current courses could be merged into a single semester-long course, so that the fall semester comprises the training phase and the spring semester the application phase where students complete and present their research projects.

## 10. CONCLUSION

We will continue our long term tracking and surveying of students both in the program and in our control group to understand ERSP's success as a retention program. However, even with our current data we are convinced of the value of ERSP. It has already proven itself a relatively low-overhead way to engage dozens of early-college students in meaningful and successful research experiences, and we believe that through ERSP these same outcomes can be achieved at other large research universities.

## 11. ACKNOWLEDGMENTS

We would like to thank the lab mentors who have participated in ERSP so far. This material is based upon work supported by the National Science Foundation under Grant No. CNS-1339335.

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