ASEE 2022 ANNUAL CONFERENCE
Excellence Through Diversity
MINNEAPOLIS, MINNESOTA, JUNE 26TH-29TH, 2022 ASEE
Paper ID #37501

An Undergraduate Research Methods Class: Results and Experiences from Initial Offerings

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Abstract: Our institution has focused on expanding the Honor's College experience in an effort to improve university recruiting and retention. Within the College of Engineering and Applied Sciences, the goal is to focus the Honors experience on undergraduate research with an aim of broadening research opportunities and competitiveness of student applications for summer research programs, NSF REUs, internal/external research funding applications, participation in undergraduate research conferences, and preparing the students for graduate school. Historically, many students (inside and outside of the honors program) have received credit for completing undergraduate research, but this is often a "stand-alone" course with no additional preparation and ill-defined outcomes. While this approach may provide a laboratory experience, the research experience is greatly dependent on the mentoring provided informally by the research laboratory and the research advisor. In addition, the Honors College would like to increase the number of students completing their Honors Capstone (senior thesis). To respond to these goals, an "Introduction to STEM Research" course was developed and taught. This course was broadly designed to group mentor the students into the research process, prepare them for the subsequent in-laboratory research experience, and scaffold them towards completion of the Honors program. This course is broadly focused to provide a general approach to research and graduate school preparation appropriate for all majors in the Engineering College and other programs in hard science.

The Research Methods course has now been taught twice: Spring 2020 and Fall 2021. While offered through the Honors College/Engineering Honors, the course was open to all interested students. For the initial two offerings, there have been a total of nine students (six engineering and three others). Course topics included: finding a research mentor, literature search skills, using the scientific method for approaching a research problem, developing a research methodology, writing a funding proposal, delivering a research presentation, and selecting and applying for graduate school. Results, experiences, observations and student feedback from these initial offerings will be presented. Most desired outcomes for the course were met. All students found one (or more) research advisors and initiated their research. The students completed the required university safety training. Several students submitted successful applications for funding or undergraduate research programs. Assessments and student outcome tracking for the course will be discussed. For example, student self-reported level of experience was compared for 12 different course topic areas before and after the course. The average response increased by 1.31 and 21 "Don't Know" responses pre-course became 0 "Don't Know" answers post-course. The largest increase was in "Find a Research Mentor." The CURE tool for examining classroom aspects of undergraduate research was also used as a tool to benchmark this course against similar approaches to exposing undergraduates to research. Comparison of CURE data to this work shows six items with very similar responses. The general result of this comparison is that the learning experiences in this course help similarly prepare students for undergraduate research as the approaches surveyed in CURE.

INTRODUCTION

Our institution has focused on expanding and broadening the Honor's College experience in an effort to improve recruiting and retention. Honor's Colleges and undergraduate research experiences are considers High Impact Practices (HIP)[1] and are broadly used in many institutions of higher education to improve recruiting and retention. Within the College of Engineering and Applied Science, the goal of the Engineering Honor's experience is to focus on undergraduate research. To complete this focus, all Engineering Honor's students will be required to take 3 credits of undergraduate research, complete a senior thesis, and deliver a research presentation.[2]

The university's Honor's College program itself would also like to, as a main goal, mentor students into research to increase the number completing the honors capstone (often a "thesis" in the STEM fields). Secondary goals are to increase the number of students involved in undergraduate research, as well as increase the number of students applying for and receiving admission to graduate school, NSF REUs, other undergraduate research funding, and regional and national conference presentations. In order to achieve these goals, the Honors College and the Engineering Honors program have elected to complement the undergraduate research with a Research Methods course. The focus of the course is to: mentor students into the research process, increase the student's ability to apply for and receive competitive funding, admissions, and conferences, and to improve the research experience and productivity of the subsequent undergraduate research laboratory course.

Undergraduate Research Methods courses are common in the socials sciences (psychology, sociology, political science, and criminal justice studies)[3-5]. These courses are focused on developing, using, and interpreting surveys. They typically consist of three main components: survey design, internal review board (IRB) approval and CITI training, and statistics and statistical analysis of the data.

While these undergraduate research methods are not as broadly available in the hard sciences and engineering, some are being offered.[6-8] Topics to improve the research experience are also starting to be incorporated into summer research experiences for undergraduates (REUs).[9] In contrast, similar research methods courses for graduate students are becoming more common and are broadly offered.[10-12] In contrast to the social science courses, the graduate courses in engineering typically include such content as literature searches, reading the literature, delivering presentations, scientific method, research ethics, proposal writing (including a research plan), patents, copyrights, and research notebooks. Many of these topics would also be relevant to an undergraduate research methods course in the hard sciences and engineering. As such, many of these topics are starting to find their way into traditional apprenticeship model undergraduate research courses where the students work in their mentors laboratory.[13, 14] However, it appears that the student is usually left to obtain this research methods knowledge individually from their research mentor. In addition, there is a combined type of research methods course. In this style of course, the students are group mentored on research methods while at the same time conducting research under the instructors mentorship.[6]

However, there are still un-resolved questions associated with undergraduate research. First, as demand grows for undergraduate research, in the current "apprenticeship mode" of sending students into the lab without additional training, the strain of this additional work on the faculty becomes evident.[15] In addition, as Gray has asked, "What skills do students need to participate in undergraduate research?", "How do these skills differ by discipline?", and "Where in the curriculum do students develop these skills?"[16] These last two items indicate one potential solution, a common introduction to research methods covering many applicable topics through a standard course.

An undergraduate research methods course for the students in the University Honor's College and Engineering Honors has been developed and delivered twice. The goal of this course is to deliver a group mentoring experience to prepare students for success in the subsequent undergraduate research course with individual research advisors/mentors. Secondary goals include increasing the number of submissions and receipt of graduate school admissions, NSF REUs, undergraduate research funds, and undergraduate research conference presentations. This work is a subsequent development of previous regional [21] and national [22] conference proceedings. In this work, the initial course offerings will be discussed, including why these topics were selected, experiences from the initial offerings, changes for future offerings, desired outcomes achieved, and assessment. In addition, results on the effectiveness of the course and its impact on students along with comparison to literature data for other approaches also designed to prepare undergraduates for research will be discussed.

METHODS

Research Methods was taught as a 3-credit undergraduate course during the Spring Semester 2020 and Fall Semester 2021. This course was taught once in Engineering Honors as ES 3890 (ES for Engineering Science) and was cross listed under each program in the college. It was subsequently taught in the Honor's College as HP 4990 (Honors Program). The course met for 42 class periods of 50 minutes each. Neither course was restricted to Engineering Honors or Honors students. This course is not required for Honors or Engineering Honors.

The general goals for this course are: (1) to provide a general approach to scientific research and graduate school preparation, and (2) to prepare the students for the subsequent Engineering Honors laboratory experience course, ES 4580 Undergraduate Research (again, cross listed across the college), or for Honor's students as either HP 4975 (Independent Study) or through the undergraduate research course number in the students home department.. These broad goals were then separated into individual learning objectives as reflected below.

Two required textbooks will be used for the course: The Craft of Research by Booth, Colomb and Williams[17], and The Craft of Scientific Presentation by Alley.[18] In addition, On Being a Scientist: Responsible Conduct in Research will be used for the research ethics discussion.[19] Lecture materials, assignments, and assessment tools are posted on the course webpage at: https://uwyo.libguides.com/honors_research_methods_es3890

Pre-course and post-course assessment were used to determine self-reported levels of (for example) experience on various course elements, science attitude questions, and overall evaluation of the experience. The previously developed and validated Classroom Undergraduate Research Experience (CURE) Survey was also used for this assessment.[20] This tool is focused on the classroom aspects of undergraduate research.

RESULTS

Two required textbooks were used for the course: The Craft of Research by Booth and Colomb,[17] and The Craft of Scientific Presentation by Alley.[18] The Booth book is focused on developing research ideas, developing a research methodology, developing an argument through evidence and reasons, and writing up the research. The Alley book is focused on the presentation of the work though both poster and oral presentations. On Being a Scientist also provides a tool for discussing research ethics as a number of vignettes are presented which allow for a broad class discussion of the ethical issues, people involved, questions to ask, and possible solutions. This is available for free in .pdf form from the National Academy Press website.[19]

Table 1. Course Schedule

Week	Class	Topic	Week	Class	Topic
1	1	Introduction/Syllabus	9	1	Research Ethics
	2	Why Undergrad Research		2	Research Ethics
	3	Finding a Mentor		3	Research Ethics
2	1	Holiday	10	1	Instructor out of town/guest
	2	Literature Searches		2	lectures/to be determined
	3	Reading the Literature		3	
3	1	Oral Presentations	11	1	What is graduate School?
	2	Oral Presentations		2	Finding a Graduate School
	3	Poster Presentations		3	Applying for Graduate School
4	1	Scientific Method	12	1	Careers with Graduate Degrees
	2	Scientific Method		2	Thanksgiving
	3	Scientific Method		3	Thanksgiving
5	1	Student Presentation	13	1	Research Notebooks
	2	Student Presentation		2	Research Notebooks
	3	Student Presentation		3	Citation Management Software
6	1	Student Presentation	14	1	Student Led Ethics Discussions
	2	Student Presentation		2	Student Led Ethics Discussions
	3	Student Presentation		3	Student Led Ethics Discussions
7	1	Undergraduate Research Opportunities	15		Final Exam week
	2	Proposal Writing			
	3	Proposal Writing			
8	1	Proposal Writing			
	2	Paper Writing			
	3	Paper Writing			

Class schedules for the initial course offerings is shown in Table 1. Planned lectures fall into the following categories: (1) Finding your research interest and finding a mentor, (2) reading papers, and writing papers and proposals, (3) scientific methods for developing a hypothesis and research plan, (4) research ethics, (5) graduate school familiarity and applying for graduate school, (6) presenting your research plans, and (7) professional skills.

Assignments for the course and the objectives for each assignment are shown in Table 2. The student work for the course falls into the following broad areas: (1) Finding your research interest and finding a mentor, (2) reading papers, and writing papers and proposals, (3) scientific methods for developing a hypothesis and research plan, (4) research ethics, (5) graduate school familiarity and applying for graduate school, (6) presenting your research plans, and (7) professional skills.

Table 1: Course Assignments

Number	Topic	Skills/Concepts Reinforced
1	Finding a Mentor	Faculty/Student Interaction
	Research Interests	Self-Reflection
	Identifying Potential Mentors	Web research
	Meeting Mentors	Oral and Written Communication
2	Literature Search	Library, Written Communication, Literature Comprehension
	Find Relevant Papers	Library, Searching Skills
	Insert Into Reference Manager	Practical Skills
	Literature Synopsis	Written Communication
3	Presentation	Oral Communication, Research Methods, Scientific Method
4	Ethics Discussion	Oral Presentation, Research Methods, Library Skills
5	Seminar/Proposal/Defense	Written communication, Research Integration, Exposure to Graduate Expectations
6	Hypothesis and Research Plan	Scientific Method, Research Integrations, Written Communication
7	Laboratory Safety	Safe laboratory practices
8	Proposal	Library, Scientific Method, Written communication
9	Poster Presentation	Oral Communication, Scientific Methods, Literature Skills, Research Integration

Following an introduction lecture, two lectures were devoted to understanding the benefits and results of undergraduate research together with finding a research mentor. This was complemented with several assignments to help the students identify their mentor. First, a reflective statement was used by the students to focus their research interests. This was followed by identification of potential mentors across the college with student comments on the positives and negatives of each of their research interests. Finally, the students met with several potential mentors and then wrote a synopsis of each researcher and their project. This concluded with the students deciding who their choice is and why that mentor was selected. A subsequent lecture later in the semester discussed standard undergraduate research opportunities such as the university course, summer research programs, and NSF REU type opportunities.

An early lecture on literature searching and literature searching tools will allow the students to find manuscripts on their advisors work and related work. Once literature was identified, the students then wrote a synopsis on each paper and how it relates to or can be used for the student's project. Finally, to initiate research skills, the students entered each manuscript into a reference manager.

While the above process of determining a research mentor and starting the literature process is ongoing, there were two lectures on oral presentations and one on poster presentations. These lectures will provide practical examples to assist in subsequent development and delivery of both types of presentations. Three lectures will then be devoted to the scientific method. This contributed to the student assignment to develop a research hypothesis and a research plan.

The first presentation was an oral presentation by the students to present a synopsis of their literature search and how the literature can contribute to their research. This reinforces the earlier lecture on reading the literature. It also further develops the literature synopsis assignment. Finally, it gives the students their first practice at a scientific presentation. The goal is to keep these presentations short to allow for immediate feedback by the instructor and their peers.

After the above-mentioned lecture on undergraduate research opportunities, students select a funded research opportunity and complete a mock application. A list of typical opportunities associated with the university was provided by the instructor, although the students are free to locate other opportunities. The goal is for the students to learn how to develop and write these applications, including a personal statement and a research plan. It is anticipated that the students will be encouraged to further develop and revise these proposals and then submit them under their mentor's guidance during the subsequent semester in their research course. To prepare the students for this work, three lectures are devoted to proposal writing. Two subsequent lectures cover writing papers. While the students are not far enough along to write up their research, thinking about writing papers and the structure of papers contributes to learning about the research process and hopefully encourage them to think what work it will take to contribute to a future manuscript.

Three lectures were focused on research ethics. "On Being A Scientist"[19] from the National Academies was used for these lectures as it provides multiple theoretical research vignettes that can be used for class discussions. These lectures are complemented by the student

assignment to lead a research ethics discussion. Students (either individually, paired-up or divided into small groups depending on the class size) then select a historical research ethics topics (list provided by the instructor), perform a literature search, prepare a synopsis for the class, and then lead a discussion in the classroom to discuss the case and present alternative approaches to prevent future recurrences of the issues.

The instructor is typically out of town in late October or early November for a professional conference. This time is filled with guest speakers or project time to work on their ethics discussion, proposal, or poster presentation. The students can also complete the on-line laboratory safety assignment during this time. The following four lectures will expose the students to graduate school, including "What is Graduate School," "Finding a Graduate School," "Applying for Graduate School," and "Careers with Graduate Degrees." This covers topics such as: 1) the focus of graduate school is the research, not just more courses, 2) apply to a school where the faculty do research in your area and not just a big-name school, and 3) who should I get to write letters (with the implied goal of cultivating this letter writer while you are an undergraduate). This is complemented with a student assignment to attend a graduate seminar and either a proposal or final defense. This exposes students to the results of research at the graduate level and beyond. The associated assignment will be a reflection on the presentation with the student identifying similarities with topics covered in this course.

Post-Thanksgiving lecture topics include research notebooks. The semester concludes with the student led ethics discussions and the final poster presentation. The poster presentations occur during the scheduled final exam time. For the poster presentation, all work from the semester will be combined. The students present a short synopsis of their research mentor and their mentor's work. However, the main body of the poster will cover the student's research hypothesis and their research plan. This also includes contributions from the literature and how the literature influenced the plan.

DISCUSSION

This course builds from similar undergraduate courses in the social sciences and graduate courses in hard sciences and engineering. While the research mentoring is similar to combined mentoring/research courses, this course is set up for the students to have separate research mentors in a subsequent course. Perhaps the most similar course to this course is presented by Balster et al.[23] Many of the topics and goals are similar with their course actually being a two semester sequence of courses meeting for one hour per week each semester.

This course was designed to support Engineering Honors but also flexible enough to broadly support STEM students and others across campus. Two students completed the course in Spring 2020 and seven students completed the course in Fall 2021. Of the nine total students, six were Engineering Honors and three were honors (two in STEM fields, one on political science). Demographics were six female and three male with no under-represented minorities.

The lectures for this course were selected to cover the broad range of topics necessary for students to determine their research interests, find a research mentor, learn skills for success in

the research laboratory, and learn how to use the tools necessary for participating in research (reading and writing publications, abstracts, proposals, and presentations). As expected, these topics are similar to the topics that are included in similar Research Methods courses for graduate students as the goal for both types of courses is improved research productivity [10-12] However, in spite of their similarities, the different level (undergraduate vs. graduate) merits a few changes in the course content. Determining research interests is more important for undergraduates as many graduate students focus their graduate school applications on their research interests. Instead of performing a critical review of the literature (graduate course), the students received instructions in reading (or "decoding") the literature. Similarly, the undergraduate course assignment focused on a proposal for summer undergraduate research program/funding, while the graduate course assignment was for a graduate funding proposal. In addition, instead of using regular journals as examples for the graduate course, the undergraduate course can use examples from undergraduate research journals as a way to make the idea of publication more accessible to these students. The last main difference between the undergraduate course and the graduate course was the focus on learning about graduate schools, graduate research, and selecting and applying for graduate schools. Clearly, this material would not be timely for graduate students.

Based on the initial offering of this course, several changes were identified for implementation in future courses. Based on student feedback, at least one class period would be scheduled early in the semester to host an undergraduate research panel discussion. The panel would consist of several undergraduate students that had completed at least one semester performing research and the audience would be the current students in the class asking questions. The panel could discuss such issues as "what struggles did you have?" what did you not know before you started that you wish you had?" and "what were your goals and accomplishments?" Again, based on student requests, guest speakers would be identified and asked to talk to the students about the GRE, MCAT, and F.E. exam, for example. In retrospect, this request should have been anticipated if course topics included topics such as "selecting and applying for graduate school." A potential speaker for the MCAT exam as already been identified from the pre-medical advising group on campus.

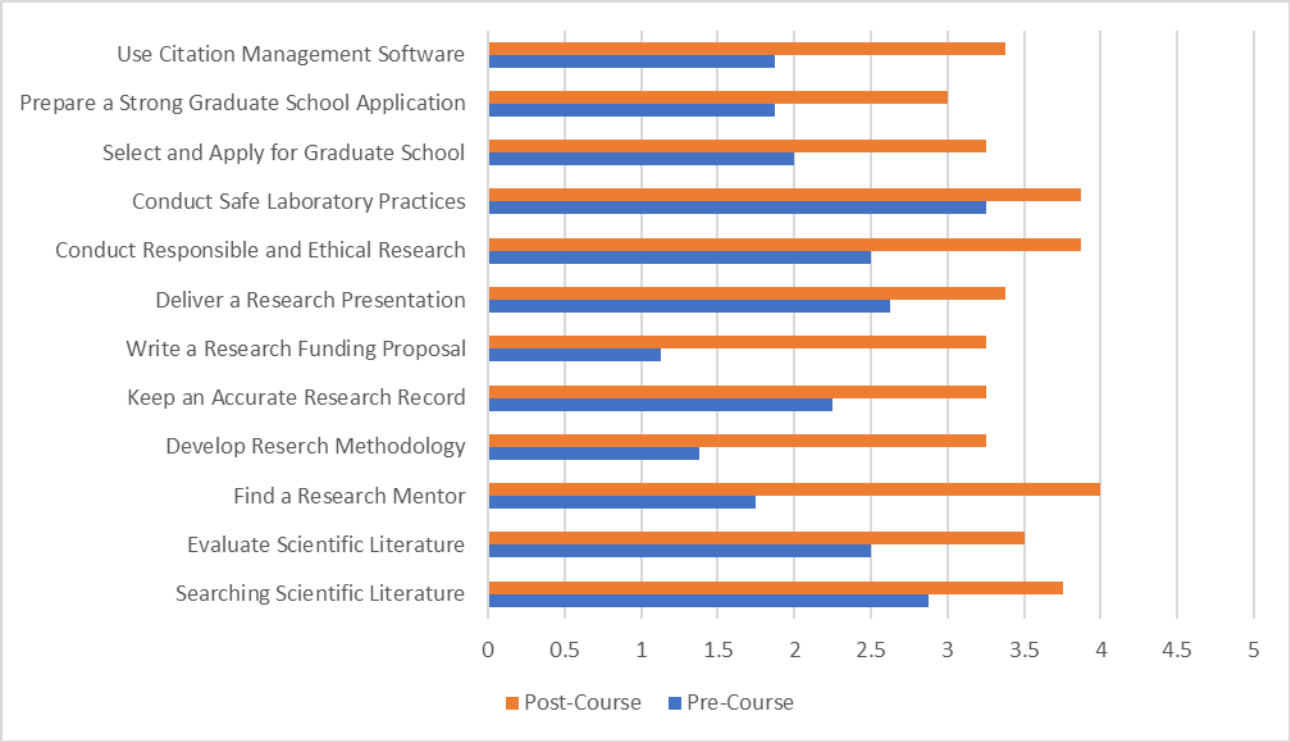
Throughout the course, a number of journal publications were used as lecture material. These are journal articles that were to be useful examples in previous courses. However, it might be beneficial to instead use (some) publications from undergraduate research journals. This would provide the student's an introduction to this body of literature and also allow them to see the amount of work required for publication, at least in comparison to normal research journals in which most articles consistent of contributions from several graduate students.

For the initial offerings of the course, outcomes in three areas were achieved. One goal of the course was for the students to identify a research mentor for the subsequent laboratory research experience. All students found a research mentor in positions ranging from volunteer to paid researcher. All students also completed all three of the university's required safety modules. This made them eligible to perform research in the laboratories. One of the course assignments was for the students to prepare a proposal for undergraduate research funding, a research experience for undergraduates, etc. In addition to simply preparing these proposals as an assignment, three students submitted these proposals. One proposal was submitted as written

for the assignment. Due to the proposal deadline, one proposal was revised and re-focused for a different application. Two students were successful; one student received NASA EPSCoR funding for research and the other student was accepted for a multi-student undergraduate research experience program. Many RFPs for student research funding are released and due during the spring semester. Thus, the fall offering of the course was off-cycle to mesh with the due dates for these submission windows.

Student self-reported levels of experience on course elements, science attitude, and overall evaluation were collected (see website for the instrument). Questions were asked in twelve different areas using a Likert type scale. For the nine students at twelve questions each, the responses went from twenty-one "Don't Know" responses pre-course to zero "Don't Know" responses post course. In addition, the average response increase by an average of 1.31 points (see Figure 1). Of these 12 areas, the largest growth appeared in "Find a Research Mentor" (2.25) and "Write a Research Funding Proposal" (2.125). This is a positive outcome as these are

Figure 1. Student Self-reported Assessments

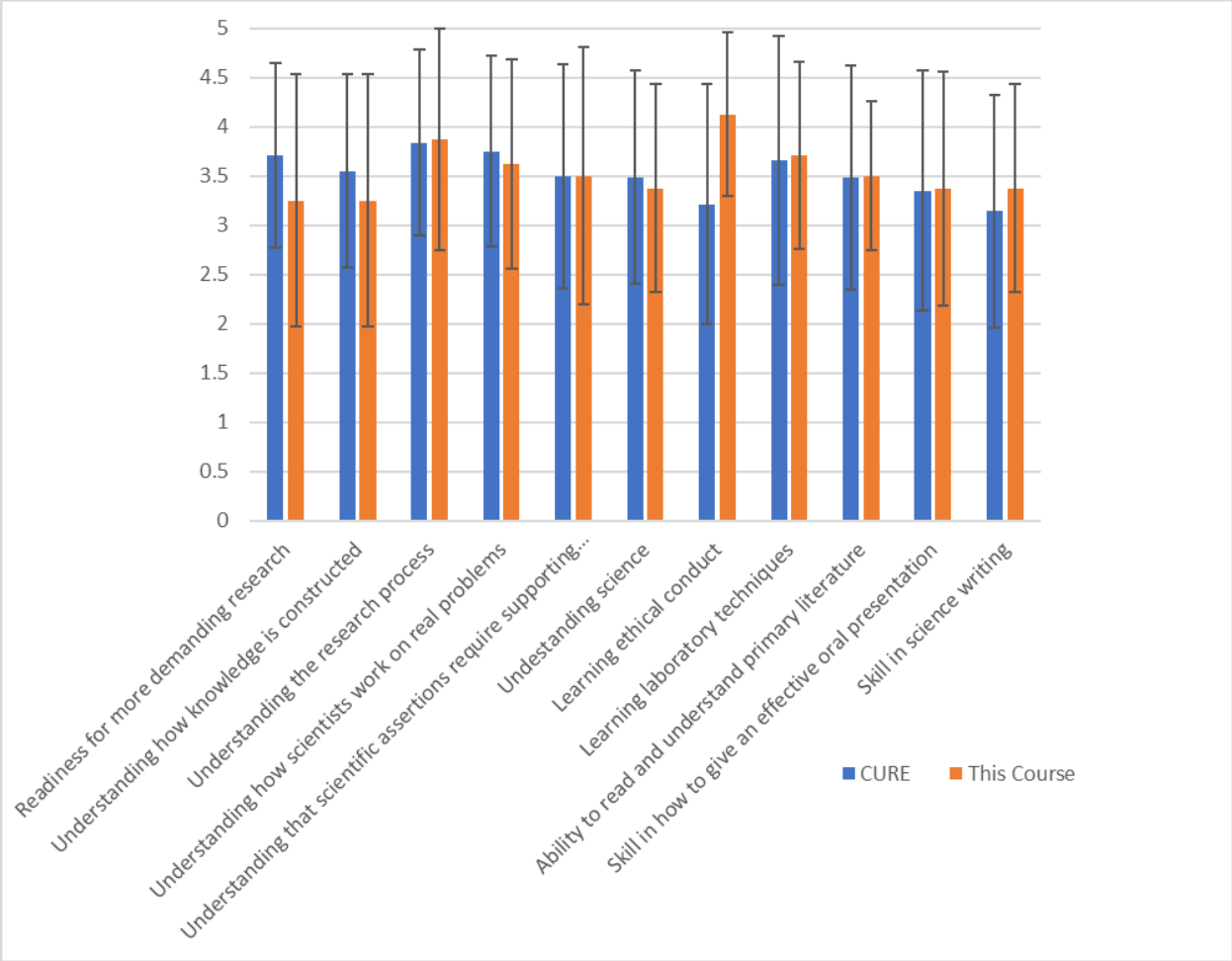


two of the main objectives of this course. "Develop a Research Methodology" (1.875) and "Use Citation Management Software" (1.5) showed the next highest increases. "Conduct Safe Laboratory Practices (0.625) and "Deliver a Research Presentation" (0.75) showed the lowest increase. This is not surprising as students cover these topics in earlier courses (e.g. most STEM students will complete university safety courses as part of introductory chemistry, physics, or biology courses).

The CURE survey provides an appropriate comparison for the outcome of this course it "may be used as pretest-posttest or posttest only survey to measure student effectiveness in

"research like" or other science courses."[20] From the CURE, all students except one (possibly the student in ROTC) indicated a desire for at least an MS degree (or similar law or medical degree), but none showed an increase (i.e., MS to PhD) from pre-course to post-course. This result may indicate that the students in this course elected to take this course already thinking about graduate school. Eleven "Benefits" from the CURE survey were selected for direct comparison with this course. These Benefits were chosen as they include topics directly covered in this course. These Benefits are compared in Figure 2. Average results from CURE and this work are shown. In addition, the standard deviations for both the CURE data and this work are shown in the figure. From this data, there are six items which show very similar average responses between CURE and this course (understanding the research process, understanding that scientific assertions require supporting evidence, learning laboratory techniques, ability to read and understand literature, skills in how to give an effective oral presentation, skills in science writing). In addition, the standard deviation for many of these similar response items is also similar. The only Benefit item with a observable difference appears to be "Learning Ethical Conduct." The CURE average was 3.21 versus 4.12 for this course. In addition, the lower standard deviation value for this item for this course was still above the average for the CURE

Figure 2. Comparison of Benefits from CURE



data. This result, while based on a limited data set, may indicate that the combination of instructor and approach for covering ethics in this course may bear further examination and comparison with ethics instructions in some of the other approaches that are included in the SURE results. In general, these results indicate that the learning experiences in this course to help prepare students for undergraduate research are similar to results from other courses and program designed to do have the same goals. As a result, this course now offers an additional tool available for use by educators that can provide a research like or research preparatory experience. Educators now have this course to use, depending on their needs and resources.

CONCLUSIONS

An "Introduction to Research Methods" course for Engineering Honors and/or Honor's College students was developed and offered twice. Total enrollment for the two offerings was nine students. High level student outcomes were met: 1) All students identified mentors for a subsequent laboratory research experience, 2) Students prepared proposals for funding and/or undergraduate research experiences (two students successfully received a total of three funded opportunities), and 3) Students completed university safety training requirements allowing them work in research laboratories. Self-reported pre- and post-course assessment of twelve items went from 21 "Don't Know" responses to zero. Average increase on the twelve items was 1.31 points on a 5-point scale. Comparison of a sub-set of "Benefit" responses between this course and the CURE survey showed that this course provided similar student gains when compared to other experiences designed to prepare students for undergraduate research.

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