A Departmental Research Methods Course to Support New Undergraduate Researchers

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Abstract

Many universities promote experiential learning opportunities for students to apply their learning outside traditionally required coursework. As one type of experiential learning, mentored undergraduate research opportunities are common across engineering. The experiences of individual undergraduates in their first research experience may vary widely based on the mentorship and training provided. Our department developed a research methods course taken in common by all new undergraduate researchers across chemical engineering labs to provide consistent training in a common set of research-specific professional skills and to build a cohort culture amongst undergraduate researchers for mutual support. The course is offered in fall and spring semesters and has been taught since 2009. Course topics in the undergraduate research methods course include basic research terminology, choosing research areas that resonate with personal interests and values and that impact society, library tools, reference management software, reading research papers, crafting poster and oral presentations, writing technical reports and statements of purpose for applications, and practicing technical communication. This paper disseminates the resources from the class for reuse in similar courses or for training cohorts participating in summer research experiences for undergraduates.

Introduction

Many universities promote experiential learning opportunities for students to apply their learning outside traditionally required coursework. As one type of experiential learning, mentored undergraduate research opportunities are common across engineering. A recent article by West and Holles [1] provides a nice overview of the literature on undergraduate research in science engineering and many practical tips and benefits for chemical engineering educators to consider regarding undergraduate research. Ford Versypt et al. have a forthcoming conference proceedings paper [2] that follows some of the best-practices advice of [1] by providing tips for using coding templates to streamline and standardize the training of new undergraduate research students in computational engineering labs. Additionally, Holles and Howe wrote a proceedings paper [3] that covers a three-credit stand-alone undergraduate research methods course that focused on preparing new undergraduate researchers to look for their first research experience. Those course topics included finding a mentor and writing a proposal to fund the research. The course at our university differs in that it focuses on students at a different stage in undergraduate research. The students have already committed to a lab and have a research mentor. In our new student orientation programs, introduction to chemical engineering (material and energy balances) course, and AIChE student chapter activities, we provide students with information on undergraduate research, ongoing research in the department, and how to approach faculty on campus to initiate undergraduate research opportunities.

The experiences of individual undergraduates in their first research experience may vary widely based on the mentorship and training provided. Our department developed a research methods course taken in common by all new undergraduate researchers across chemical engineering labs to provide consistent training in a common set of research-specific professional skills and build a cohort culture amongst undergraduate researchers for mutual support. The course is offered in fall and spring semesters and has been taught since 2009.

In our undergraduate research course, students concurrently take one credit in the department-wide undergraduate research methods course, which we refer to as the lecture section, and two credits of independent study with the research mentor (the laboratory section). Course-based undergraduate research experiences (CURE) have been used elsewhere [4], where the lecture instructor also guides all of the students in the instructor's research laboratory. Distinctly in our approach, each faculty member in the department can guide undergraduates in their own corresponding laboratory sections, while the lecture section is taught centrally by one instructor per term with a common set of materials passed between instructors in subsequent terms. Separate grades are given for the lecture and laboratory sections.

Course topics in our undergraduate research methods course include basic research terminology, choosing research areas that resonate with personal interests and values and that impact society, library tools, reference management software, reading research papers, crafting poster and oral presentations, writing technical reports and statements of purpose for applications, and practicing technical communication. Some instructors also cover topics of how and why research is funded and survey research facilities on campus. Students gain experience with evaluating journal articles and the presentations of their peers. Students also learn more about other labs and find peers who are engaging in research for the first time. This can be quite powerful when they might be the only undergraduate in their lab or are exposed only to those with more experience than them. We do not cover topics of data analysis or statistics in this course. All undergraduates have required statistics and numerical methods courses in the department, as well as data analysis and experimental design topics in our sequence of laboratory courses.

This paper aims to disseminate the resources from the lecture section of the undergraduate research course and to share another paradigm for supporting undergraduate researchers as they engage in their first researched-based experiential learning opportunities. Other engineering educators may be interested in creating a similar course to complement existing undergraduate research for course credit or to supplement the training provided to participants in summer research experiences for undergraduates. Please contact the first author for electronic access to additional course materials, including lecture slides, writing style guides, assignment files, and a Google form version of the presentation rubric.

Course History and Implementation

In spring 2009, our faculty voiced concerns regarding discrepancies in the experiences that students had performing research in different faculty labs, which is a sentiment also expressed by Holles and Howe [3]. Our department was interested in establishing general guidelines for activities that all undergraduate research students should participate in. Examples included completing a written report, oral presentation, literature review, etc. The department's undergraduate committee discussed the issue and decided to split the undergraduate research for course credit experience into two integrated courses, with department approval, in May 2009. Fall 2009 was the first semester we required the 1-hour lecture component. The lecture section brings together all chemical engineering students participating in undergraduate research for the first time. This portion of the research experience ensures that all students complete a minimum set of tasks, including writing a paper and giving a presentation regarding their research. We had found that students were migrating towards certain professors that had "easier" standards than others regarding undergraduate research for course credit. Thus, part of the original motivation was to normalize grading expectations for undergraduate research independent study for course credit. Having the one-credit common experience does not eliminate the variability in expectations among research advisors, but it certainly reduces it. More importantly, all the students develop a baseline set of research skills and exposure to aspects of research that they might otherwise miss, depending on the level of mentorship provided by faculty or other researchers in the lab. Bringing the students together weekly allows them to compare experiences and think about what a good experience looks like. Through the lecture section, all students must complete a written report (formatted as a journal article) and deliver an oral presentation during our "Research Fair." The laboratory section is faculty-specific. It is via this section that students work in research laboratories. The undergraduate committee also developed a rubric for research advisors to evaluate performance in the research laboratories (Appendix A).

The one-credit lecture section for the undergraduate research course has been offered in fall and spring terms since 2009, for 30 offerings to date serving 319 students (Table 1). 104 (32.6%) of the students who have taken the course are female. Other demographic data are presented in Table 2. Students typically perform well in the course (75.3% A's and 16.0% B's aggregated across Fall 2009-Fall 2023, Figure 1), but effort is required to earn the grades (Figure 1). Eight instructors have led the department-wide one-credit lecture section. This is just over 25% of the department's current faculty. The authors of this manuscript are Professors Errington, Kofke, Swihart, Ford Versypt, and Sepesy. The average number of terms each instructor has taught the course is 3.75 semesters. Professors Errington, Kofke, and Park taught the course ten, nine, and five terms, respectively. All others have taught the course for one term, except for Professor Ford Versypt for two terms. Professors Ford Versypt and Sepesy will likely continue teaching the course in the fall and spring semesters, respectively. The enrollment per term has varied between 2 and 19 students, with an average of 10.6 students/term. We do not observe any definitive correlation between the research course enrollment and the department enrollment on a term-by-term basis. However, enrollment in the department has decreased post-pandemic. We observe that the spring enrollment has tended to be larger than that in the fall semester in the same academic year (9 of 15 times total and 9 of the last 11 years, Figure 2).

Table 1: Department-wide one-credit lecture section of the undergraduate research course enrollment and instructors by semester in the 15-year period of Fall 2009-Spring 2024.

Semester	**Instructor**	**Enrollment**
Fall 2009	Professor Errington	16
Spring 2010	Professor Errington	9
Fall 2010	Professor Errington	11
Spring 2011	Professor Errington	5
Fall 2011	Professor Errington	7
Spring 2012	Professor Errington	4
Fall 2012	Professor Errington	12
Spring 2013	Professor Errington	10
Fall 2013	Professor Errington	15
Spring 2014	Professor Errington	19
Fall 2014	Professor Kofke	12
Spring 2015	Professor Kofke	15
Fall 2015	Professor Kofke	14
Spring 2016	Professor Kofke	13
Fall 2016	Professor Kofke	10
Spring 2017	Professor Kofke	15
Fall 2017	Professor Kofke	17
Spring 2018	Professor Kofke	16
Fall 2018	Professor Lupion	9
Spring 2019	Professor Courtemanche	16
Fall 2019	Professor Park	9
Spring 2020	Professor Park	11
Fall 2020	Professor Park	2
Spring 2021	Professor Park	8
Fall 2021	Professor Park	5
Spring 2022	Professor Swihart	9
Fall 2022	Professor Ford Versypt	7
Spring 2023	Professor Kofke	10
Fall 2023	Professor Ford Versypt	6
Spring 2024	Professor Sepesy	7
sum	Eight faculty	319 students
average	3.75 terms/faculty	10.6 students/term

Table 2: Racial/ethnic demographics for the department-wide one-credit lecture section of the undergraduate research course aggregated across Fall 2009-Spring 2024.

Race/Ethnicity	**Number**	**Percentage**
Two or More Races	10	3.1
Native American	1	0.3
Asian	52	16.3
Black or African American	16	5.0
Hispanic/Latino	23	7.2
International (Non-Resident Alien)	66	20.7
Unknown	23	7.2
White	128	40.1

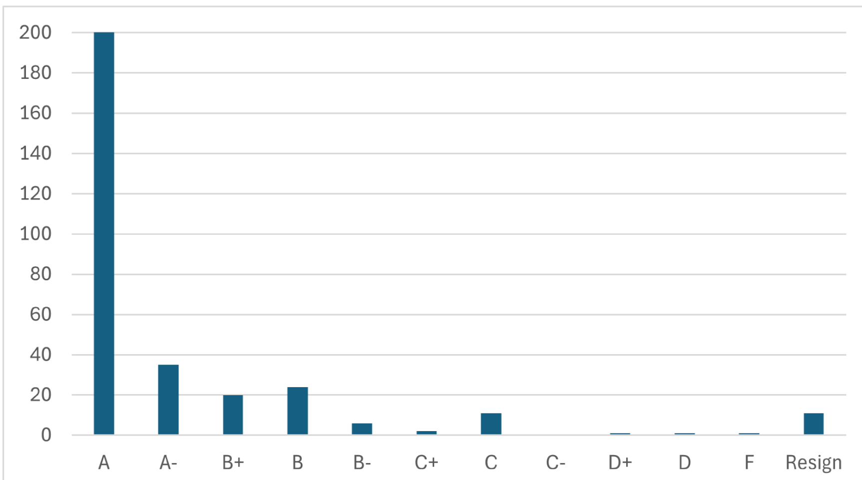

Figure 1: Final grade distribution aggregated across Fall 2009-Fall 2023 for the department-wide one-credit lecture section of the undergraduate research course.

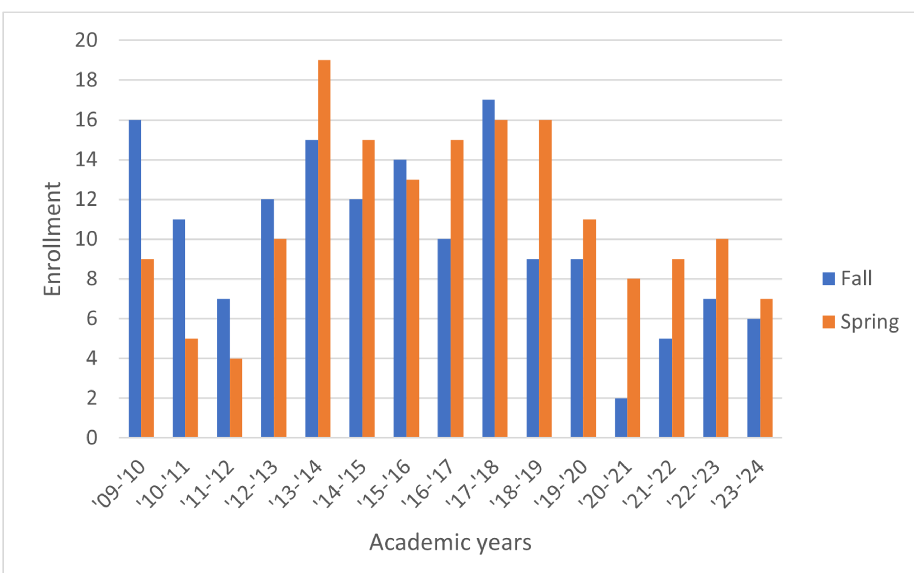

Figure 2: Enrollment over time compared between fall and spring semesters each of 15 academic years for the department-wide one-credit lecture section of the undergraduate research course.

When the change was made to create the one-credit course in 2009, a formal classroom research study was not designed or conducted to evaluate two cohorts of students: one that followed the recommended paradigm and another that did not. However, rubrics for oral communication and written communication were used by Professor Errington and the faculty mentoring students through their laboratory sections (Appendix A). Results were positive and incorporated into the department's 2014 ABET evaluation. However, the numerical values of these assessments are no longer available ten years later. Overwhelmingly, this has been a positive initiative in the department, hence its longevity. Anecdotally, several of the instructors have experienced the before and after (either at this institution or with the previous mode at other institutions) and vastly prefer the lecture-based training paradigm for consistency and camaraderie in the undergraduate research experiences in the department.

Professors Kofke and Ford Versypt discuss undergraduate research with incoming chemical engineering first-year and transfer students during orientation in the fall semester. Multiple of these students have subsequently enrolled in the undergraduate research course the following spring (or later). In the last three years, Professor Ford Versypt has taught the materials and energy balances course, the first course in the major. Undergraduate research opportunities are mentioned multiple times in that course through professional development activities. Several students then enroll in the spring semester of undergraduate research as the first term after they have heard about these opportunities and have started meeting faculty through courses and advising. Mandatory faculty advising meetings for course enrollment begin in the fall of the 2nd year, and we encourage all faculty to discuss undergraduate research during these meetings with their academic advisees. Fall recruitment has been helped in recent years by emailing all undergraduate students and faculty in the department in the week preceding the fall term to remind them about research opportunities and this course. We also encourage students who conduct summer REUs to get course credit during the academic year to take advantage of local opportunities for new research or to get credit for related faculty-supervised experiences off campus. Additionally, the university has an online portal called the Experiential Learning Network (ELN), where faculty and staff can post opportunities for research and other creative and experiential activities. Students can search for opportunities through the ELN and apply for funding for the experiences or related conferences through the ELN and other campus programs.

Course Materials

Note that this section is adapted directly from the Fall 2023 course syllabus and lecture materials, which were iteratively developed by all the instructors over the course's 15-year history.

Course description, credits, and learning objectives

CE 498 Undergraduate Research and Creative Activity is a three-credit course: one credit for department-wide lecture course (section 123) and two credits for independent study laboratory experience supervised by faculty research mentors (a separate section available for each faculty member with each section labeled by an abbreviation of the corresponding faculty member's last name). A maximum of six credits can be taken over two terms, but only three credits may be applied to satisfy degree requirements (it can count as a technical elective). In the first term of the lecture course, students must be concurrently enrolled in two credits of the laboratory section corresponding to their research advisor. In an optional second term, students enroll in three credits in the laboratory section and do not retake the lecture course. Prerequisites are permission of instructors (lecture and laboratory sections). Typically, students are chemical engineering majors or students from other majors conducting research in the labs of chemical engineering faculty. Table 3 lists course learning outcomes for the lecture section. The learning outcomes are mapped to ABET Student Outcomes [5].

University catalog description: Students collaborate with faculty research mentors on an ongoing faculty research project or conduct independent research under the guidance of a faculty member. This experience provides students with an inquiry-based learning opportunity and engages them as active learners in a research setting.

Table 3: Course learning objectives for the department-wide one-credit lecture section of the undergraduate research course. The goal statements generally complete the sentence "Upon completing this course, students should be able to..."

	Course Learning Objectives	**Student Outcome [5]**	**Assessment Methods**
1	Understand the mechanisms used to disseminate research results	3	Homework
2	Understand the steps involved in the publication of peer-reviewed journal articles	3	Homework
3	Use Web of Science and Google Scholar to find journal articles related to a research area	7	Homework, Project
4	Use Web of Science and Google Scholar to find citation metrics associated with an author	7	Homework
5	Use SciFinder to find journal articles and patents related to a research area	7	Homework, Project
6	Independently acquire knowledge related to the selected research project	7	Project
7	Communicate thoughts, ideas, and results clearly to group members	3	Project
8	Communicate project motivation, background, approach, and results via a written technical report	3	Project
9	Communicate project motivation, background, approach, and results via an oral presentation	3	Project
10	Demonstrate a knowledge of contemporary issues associated with their research project	2	Project
11	Describe the broader societal impact of their research project	2	Project
12	Design and conduct (physical or computational) experiments and analyze and interpret data related to the selected research project	6	Project
13	Solve technical problems related to selected research project	1	Project

General Course Structure

The lecture course meets one time weekly for 50 minutes. After each class period, homework assignments engage students in the lecture material and require students to apply a relevant concept to their research project. The lecture section is delivered primarily as a traditional in-person lecture course. A hybrid flexible ("hyflex") mode is also available to students with class periods live-streamed on Zoom and recorded. Students can engage synchronously in face-to-face or online formats (using either format throughout the course at their discretion), and the recordings are made available for asynchronous learning. All are encouraged to participate synchronously face-to-face as the preferred mode or online if needed. Occasional lectures are provided either completely online (virtual) or as recordings (no in-person option), determined by the instructor's university-related travel schedule (e.g., research conferences) or based on the health/quarantine status of the instructor or other unforeseen events. No textbooks are required. All required reading materials are provided, or links to library resources are shared.

A weighted average grade in the one-credit lecture course is calculated as follows:

30% Homework assignments and class participation (15 worth 2% each)
30% Final oral presentation
40% Written report

The grade in the two-credit laboratory section supervised by a research mentor is determined by expectations discussed with that research mentor.

A typical course schedule from the fall semester is shown in Table 4.

Assignments

Homework is assigned weekly during the semester, and submissions are accepted electronically through the learning management system. Most assignments involve two parts: summarizing the previous lecture (participation assessment) and doing a related follow-up activity. The lecture summary portion follows a simple prompt: "List three key things you learned in Lecture _," where the blank is the lecture number from the most recent class period. With lecture recordings, students can complete the lecture summary after either attendance in class or synchronous or asynchronous viewing of the lecture livestream/recording. Generally, these assignments are graded on the percentage of the tasks completed.

<u>Homework assignment 1</u> tasks students with a follow-up activity to create a personal introduction to facilitate getting to know one another. Students may choose any combination of the following media formats:

1. 1-page written document
2. 1-3 slide presentation
3. 2-5 min video (screen capture, webcam capture, or both)

Table 4: Course schedule, lecture topics, and references for the lecture materials.

Lecture	Course Event or Deadline	Lecture Topic	References
1	First day of class	Syllabus, introductions, and definitions of research	[6]
	No class for Labor Day; Hwk 1 Due	Out of class: safety training and responsible conduct of research training	
2	Hwk 2 Due	Research topics and basic vs. applied STEM research	[6]
3	Hwk 3 Due	Guest lecture from librarian: databases including Web of Science, Google Scholar, SciFinder-n, and PubMed and resources for learning EndNote	[7-9]
4	Hwk 4 Due	How to find research papers, review articles, and scientific images	
5	Hwk 5 Due	Reading a research paper	[10-16]
	No class for Fall Break		
6	Hwk 6 Due	Journal club: 5 min student presentations about published research papers	[17-19]
7	Hwk 7 Due	Guest lecture from staff at career center, graduate college, writing center, or fellowships office: Personal statements for graduate school and scholarship applications	[20-22]
8	Hwk 8 Due	How to give a scientific presentation using the assertion-evidence approach	[23-26]
9	Virtual class due to AIChE; Hwk 9 Due	How to give an effective research poster and conference overview	[27, 28]
10	Hwk 10 Due	Developing non-technical professional skills	[29-35]
11	Hwk 11 Due	Writing a scientific paper and the hourglass structure of a paper from Fig. 4.2 in [36]	[36-38]
12	Hwk 12 Due	Practice for oral presentations or optional additional lecture topics if enrollment is small	
13	Hwk 13 & Hwk 14 Due	Practice for oral presentations	
14	Hwk 15 Due	Practice for oral presentations	
Finals Week	Research Fair = Oral Presentation; Written Report Due		

The introduction should include the following aspects:

- Preferred first and last name
- Pronouns
- A photo (or video). This should either be a headshot or a selfie taken recently.
- Year in school. E.g., third year, fourth year, etc.

- Laboratory research advisor's name and general research area (bio, computing, materials, etc.)
- A short statement explaining motivations for taking this course.
- Three to five aspects representing the student's identity (e.g., personal life, family, career interests, hobbies, background, etc.). These aspects can be presented in written, spoken, and visual form.

Submissions are posted via a discussion board in the learning management system. The instructor also provides an introduction. After the introduction assignments are due, students are strongly encouraged to look through those of classmates on the discussion board.

Homework assignment 2 (safety training) is required for all, and the research laboratory instructor may require safety training well in advance of the deadline for Homework 2. The safety training includes the Lab Safety Training session offered by the institution's Environment, Health & Safety office, which is required annually for all students, faculty, and staff conducting research. Depending on the lab, the laboratory instructor may require safety training beyond the EH&S Lab Safety Training program. All students, whether working in a laboratory or not, must also complete the electronic course for Responsible Conduct of Research CITI Training. Homework assignment 2 in the fall semester follows when the class period falls on the Labor Day holiday. Rather than summarizing a lecture, students read the Introduction and Chapter 1 of Where Research Begins: Choosing a Research Project That Matters to You (and the World) [6] and list three key things they learned from the reading. This book is available as an electronic book through our institution's library, so students are not required to purchase it.

The follow-up activity for Homework assignment 3 prompts students to move from a research topic to questions. In the next assignment, they will use sources to identify the problem motivating the questions. To be ready for that assignment, they need to have questions first. After using any of the techniques discussed in Lecture 2 and Chapters 1 and 2 of [6], students are asked to provide written responses to the following prompts:

1. Identify a topic (e.g., "cancer"). This is generally the subject of your current UG research project or lab.
2. What interests you about the topic?
3. Why are you drawn to aspects of the topic?
4. What repels you about aspects of the topic?
5. What questions have you generated so far about your topic? (list at least three questions)

Homework assignment 4 builds on a visit from the university's chemical engineering subject matter librarian to introduce tips for using databases for searching for scientific articles, articles, and datasets. The librarian maintains an online guide to library resources for chemical engineering research [7]. Materials about reference management software are also shared [8, 9].

The following information is shared with the students. Based on the guest lecture from the librarian, you now know how to use databases to find sources. We will use those sources to identify the problem motivating your research questions. Using at least one of the tools discussed in Lecture 3, find at least three published research papers (review articles are allowed) that relate to the topic and the questions you asked in the previous assignment, mainly related to the background information on the topic. For each paper, answer the following:

1. Which database (e.g., PubMed, Web of Science) did you use to find this source?
2. Which keyword(s) did you use in the database for finding this source?
3. What is the paper's digital object identifier (DOI)? It is highly recommended to save a PDF copy of the paper in your class folder on your computer to access it again quickly.
4. How many citations does the paper have so far?
5. After skimming the paper, provide a one-sentence summary of the article in your own words.
6. What is one thing that you learned from the paper?

Homework assignment 5 asks students to further explore the background of their research area by finding at least one published review article related to the topic and the research questions identified by the students in Homework 3. Additionally, they are asked to conduct a Google image search related to the topic and find at least one published research article that contains one or more of the figures from the Google image search. Students must answer the same questions for the review article and the source of the figure as they did for the other research articles in Homework 4.

Homework assignment 6 prompts students to prepare a 5-minute oral presentation about one of the papers they have identified about their research topic to present in a journal club during the next class period. Specific instructions concerning the content of the presentation are provided.

Homework assignment 7 is a mid-semester check-in for informal early feedback. Students are asked to answer the following:

1. Are there any specific topics that you would like to see covered in this class to help you develop skills for your research project? If so, please suggest some.
2. How is your research experience with your research mentor going? Are there any challenges that are limiting your research experience? Are there any aspects of the research experience that have been particularly beneficial/positive for you so far?

Homework assignment 8 tasks students with drafting a one-page personal statement/statement of purpose for either graduate school or a scholarship/fellowship. This assignment follows a lecture on personal statements.

Homework assignment 9 is designed to help students start their drafts of the final oral presentation by outlining the “single premise” for each slide, as discussed in [26]. This is consistent with the “assertion evidence” approach [23-25] mentioned in Lecture 7. Students are prompted with the following instructions: Starting from a blank PowerPoint file, include eight slides as an outline (no title slide or graphical transition slide yet). For each of the eight slides, provide the following:

- One sentence premise for what you want to assert on the slide
- A draft of the evidence that supports the assertion. For now, these can be text, bullet points, sketches, or descriptions of possible images.

The goal here is to brainstorm the outline for your final presentation and then to work on adding compelling visual evidence before your practice presentation to the class and the final presentation to a public audience.

Homework assignment 10 follows asynchronous video content on poster presentations and conference best practices. After watching the content, students are asked to search for one or more conferences or local oral/poster presentation opportunities for researchers in their project area or for undergraduates in STEM and to provide the names of at least two such opportunities within the next year.

Homework assignment 11 aims to get students to properly cite their references for the final written report for the course. They are reminded of the EndNote materials shared earlier in the semester [8, 9] and asked to use them. For this assignment, they must type at least three single-spaced paragraphs of background information about their research project with at least five references cited using EndNote for either the IEEE or NIH citation styles.

In addition to the typical lecture summary, Homework assignment 12 provides students with instructions for the upcoming practice and final presentations. The graded follow-up activity is simply to sign up for both a practice and a final presentation time.

Homework assignment 13 has students extend a draft of the final written report to reach at least three total pages long (double-spaced Times New Roman 11-point font, 1" margins top/bottom/left/right). In Homework assignment 11, they drafted the background section. Here, that background is combined with an outline with at least a few sentences for each major section: Introduction (includes Background and Broader Impacts subsections), Materials and Methods, Results, Discussion, and Conclusions. The content of this draft document is not scored, but the length is graded. The purpose is to have some accountability on filling in the content towards the nine-page full report.

Homework assignments 14 and 15 task students to use the final oral presentation checklist rubric (see Appendix B for the Google form) to provide structured feedback to each peer's oral presentations during two in-class practice sessions in the weeks preceding the research fair (described below). This gives the students practice providing feedback on scientific research and familiarizes them with the items in the rubric. The rubric is designed as a checklist for quickly evaluating which aspects are true about the content, delivery, and visuals used in a presentation. Only the instructor sees the names. Collected feedback is provided after class to the presenters to share open-ended feedback and to show where they got checkmarks; a missing checkmark indicates an area for improvement before the final presentation.

Research fair/final oral presentation

The research fair serves as a public presentation opportunity and has been a part of the course since its inception. The research fair is held towards the end of the semester in finals week or the preceding week. All students must participate in the research fair by giving an oral presentation, typically 10-15 minutes in length (the event lasts 2-4 hours, depending on enrollment). Students earning course credits for internship experiences also present in the research fair. A feedback rubric is provided in advance for use by the instructor and other students in the class. The instructor also evaluates practice and final presentations using the form. The presentation is graded on participation and consideration of whether or not they incorporated at least some of the feedback provided from the practice session by the instructor and peer evaluations using the rubric. The final presentation by each student need not focus on the results they generated; instead, it can provide an overview of their project topic. The goal is for students to gain experience presenting and demonstrating what they have learned during the research course.

Students are expected to attend as much of the research fair as their schedules allow. We invite all undergraduate students to this event. The intention is to motivate other students to pursue research experiences. The primary attendees are research supervisors and the other students enrolled in the undergraduate research and internship for credit courses.

Instructions to the students for the final presentation from Fall 2023 (note that the times are adjusted based on the total number of participants):

- Prepare a 10-minute presentation.
- There will be a 3-minute question and answer period in the final presentation.
- The content of the presentation should be consistent with the final written report
- Use the assertion-evidence approach [23-25](discussed in Lecture 8 Presentation Best Practices)
- Include an introduction, results, discussion, and conclusion. A typed table of contents slide is not useful. A graphical outline may be helpful but is not required.

Written report

Each student must write a report formatted as a journal article according to the requirements listed below. The written report is due on the same day as the oral presentation. Lectures during the term explain journal articles, reference management, and writing a paper. An additional style guide of formatting, grammar, and scientific writing tips is provided to the students as part of the assignment. This final report is graded on completion (nine full pages with the required sections = 100%). Students submit intermediate drafts of report sections during the semester to provide some structured accountability for progress.

Content requirements for the written report include the following:

- Title
- Abstract
- Introduction
  - Background
  - Broader Impacts (societal impact, ethics, safety, environment, and other contemporary issues)
- Materials and Methods
- Results
- Discussion
- Conclusions

- References (use EndNote: all author names, article title, journal title, volume, page numbers, year). Generally, ACS, IEEE, or NIH are reasonable scientific reference styles in EndNote.

Note that within the Introduction section of the report the student is asked to write a paragraph on “Broader Impacts” that addresses each of the following topics:

- Contemporary issues: describe current events, trends, initiatives, common goals, concerns, and activities within the group’s area of research.
- Societal impact: describe the importance of and broader impact of the group’s research activities in today’s world.
- Ethics: describe any ethical concerns related to the group’s area of research.
- Safety: describe the safety concerns relevant to the group’s area of research.

Format requirements for the written report include the following:

- 8.5”x11” paper
- Times New Roman 11 pt font
- Double spaced
- All text must be typed, not handwritten
- Minimum nine pages, excluding the abstract and references
- Bold headings and subheadings
- No giant white space gaps between sections or at the bottom of pages
- Margins: 1 inch on top/bottom/left/right

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References

[1] C. W. West and J. H. Holles, "Undergraduate Research in Chemical Engineering: Benefits and Best Practices," *Chemical Engineering Education,* vol. 57, no. 4, pp. 215-223, 2023.

[2] A. N. Ford Versypt, C. V. Cook, and A. N. Johns, "Interactive Coding Templates for Courses and Undergraduate Research Using MATLAB Live Scripts," in *34th European*

Symposium on Computer Aided Process Engineering and 24th International Symposium on Process Systems Engineering (ESCAPE34-PSE24), Florence, Italy, 2024.

[3] J. H. Holles and L. A. Howe, "An Undergraduate Research Methods Class: Results and Experiences from Initial Offerings," in *ASEE Annual Conference*, Minneapolis, MN, 2022.

[4] N. Depaola *et al.*, "ENGR497-An introduction to research methods course," in *ASEE Annual Conference*, Seattle, WA, 2015.

[5] ABET. "Criteria for Accrediting Engineering Programs, 2019 – 2020." https://www.abet.org/accreditation/accreditation-criteria/criteria-for-accrediting-engineering-programs-2019-2020/#GC3 (accessed Feb. 01, 2024).

[6] T. S. Mullaney and C. Rea, *Where Research Begins: Choosing a Research Project That Matters to You (and the World)*. University of Chicago Press, 2022.

[7] E. Rowley and University at Buffalo Libraries. "Chemical & Biological Engineering Research: Home." https://research.lib.buffalo.edu/chemical-biological-engineering (accessed Feb. 01, 2024).

[8] University at Buffalo Libraries. "EndNote Basics." https://research.lib.buffalo.edu/endnote-basics (accessed Feb. 01, 2024).

[9] University at Buffalo Libraries. "EndNote Basics: Videos and Handouts." https://research.lib.buffalo.edu/endnote-basics/videos_and_handouts (accessed Feb. 01, 2024).

[10] A. Ruben. "How to read a scientific paper." https://www.science.org/content/article/how-read-scientific-paper-rev2 (accessed Feb. 01, 2024).

[11] H. Waters. "How to Read an Academic Article." https://docs.google.com/presentation/d/16XTjMgGRA55ISGVykjISPoYCa3vwW6_6/edit?usp=sharing&ouid=107713380664754832267&rtpof=true&sd=true (accessed Feb. 01, 2024).

[12] R. A. Callcut and R. D. Branson, "How to Read a Review Paper," *Respiratory Care,* vol. 54, no. 10, pp. 1379-1385, 2009.

[13] Utah State University Libraries. "Anatomy of a scientific article." https://usu.instructure.com/courses/45089/pages/anatomy-of-a-scientific-article (accessed Feb. 01, 2024).

[14] London School of Economics and Political Science. "How to read and understand a scientific paper: a guide for non-scientists." https://blogs.lse.ac.uk/impactofsocialsciences/2016/05/09/how-to-read-and-understand-a-scientific-paper-a-guide-for-non-scientists/ (accessed Feb. 01, 2024).

[15] R. Perkins and WikiHow. "How to Summarize a Journal Article." https://www.wikihow.com/Summarize-a-Journal-Article (accessed Feb. 01, 2024).

[16] F. Lelli. "How to Read Scientific Papers Quickly and Effectively." https://francescolelli.info/thesis/read-scientific-papers-quickly-and-effectively/ (accessed Feb. 01, 2024).

[17] J. Cham. "Journal Club." https://phdcomics.com/comics/archive.php?comicid=962 (accessed Feb. 01, 2024).

[18] J. Cham. "Journal Club, pt. 2." https://phdcomics.com/comics/archive.php?comicid=963 (accessed Feb. 01, 2024).

[19] J. Cham. "Journal Club, pt. 3." https://phdcomics.com/comics/archive.php?comicid=964 (accessed Feb. 01, 2024).

[20] B. K. Ige and UCLA Graduate Division. "Steps to Success: Writing a Winning Statement of Purpose." https://grad.ucla.edu/asis/agep/advsopstem.pdf (accessed Feb. 07, 2024).
[21] NSF Graduate Research Fellowship Program. "Personal, Relevant Background and Future Goals Statement and Graduate Research Plan Statement." https://nsfgrfp.org/applicants/statements/ (accessed Feb. 07, 2024).
[22] UBuffalo Fellowships and Scholarships. "NSF GRFP 2022 Workshop Series Part 2: The Personal Statement." https://www.youtube.com/watch?v=3wGJ6mA5qb0 (accessed Feb. 07, 2024).
[23] M. Alley. "Assertion-Evidence Classroom Teaching Slides." http://writing.engr.psu.edu/AE_Classroom_Teaching_Slides.pptx (accessed Feb. 07, 2024).
[24] M. Alley, *The Craft of Scientific Presentations: Critical Steps to Succeed and Critical Errors to Avoid*, 2nd ed. Springer, 2013.
[25] M. Alley. "Tutorial on Creating an Assertion-Evidence Presentation." https://www.assertion-evidence.com/tutorial.html (accessed Feb. 07, 2024).
[26] U. Alon, "How to Give a Good Talk," *Molecular Cell,* vol. 26, no. 2, pp. 165-167, 2009, doi: https://doi.org/10.1016/j.molcel.2009.10.007.
[27] M. Pilvankar. "How to deliver effective research posters." https://youtu.be/2L6trywEMjA (accessed Feb. 07, 2024).
[28] A. N. Ford Versypt. "Conference Best Practices." https://youtu.be/2L6trywEMjA (accessed Feb. 07, 2024).
[29] A. N. Ford Versypt, "Self-reflection assignments for evaluating non-technical skills and setting goals for professional development," presented at the ASEE Annual Conference, Columbus, OH, 2017.
[30] A. N. Ford Versypt, "Self-evaluation and reflection for professional development of chemical engineering students," *Chem Engr Ed,* vol. 53, no. 3, pp. 157-161, 2019.
[31] C. S. Dweck and E. L. Leggett, "A Social-Cognitive Approach to Motivation and Personality," *Psychological Review,* vol. 95, no. 2, pp. 256-273, 1988.
[32] Mindset Works. "Why Do Mindsets Matter." https://www.mindsetworks.com/Science/Impact (accessed Feb. 07, 2024).
[33] S. R. Covey, *The 7 Habits of Highly Effective People: Powerful Lessons in Personal Change*, 2nd ed. Free Press, 2004.
[34] J. A. Hobin, C. N. Fuhrmann, B. Lindstaedt, and P. S. Clifford. "So You Think You Have Skills." https://www.science.org/content/article/so-you-think-you-have-skills (accessed Feb. 07, 2024).
[35] C. Duhigg, *The Power of Habit: Why We Do What We Do in Life and Business*. Random House, 2012.
[36] J. Schimel, *Writing Science: How to write papers that get cited and proposals that get funded*. Oxford University Press, 2011.
[37] A. H. Hofmann, *Scientific Writing and Communication: Papers, Proposals, and Presentations*, 5th ed. Oxford University Press, 2022.
[38] J. Schimel. "Writing Science Getting Started Group Exercise." https://schimelwritingscience.wordpress.com/2021/10/06/writing-science-getting-started-group-exercise/ (accessed Feb. 07, 2024).

Appendix A

Undergraduate Research Rubric

Student: ________________________ **Advisor: __________________________**

Topic	Highly Deficient (0)	Somewhat Deficient (1)	Somewhat Proficient (2)	Highly Proficient (3)	Student Score
Ability to Design and Conduct Experiments, Analyze and Interpret Data	Student is incapable of developing plan for data gathering. Data are not documented. Student cannot operate instrumentation and process equipment. Student makes no attempt to relate data to theory. Student is unaware of measurement error.	Student develops a illogical, rather inefficient, experimental plan for gathering data. Data are seldom documented. Student requires frequent supervision to operate instrumentation and process equipment. Student struggles to apply appropriate theory to data, and often misinterprets physical significance of theory or variable involved. Student is aware of measurement error, but is rarely able to account for it statistically.	Student develops a simplistic, slightly inefficient, experimental plan for gathering data. Most data are documented. Student is tentative in operation of instruments and process equipment, but can do so independently. Student applies appropriate theory to data , but sometimes misinterprets physical significance of theory or variable involved. Student is aware of measurement error and is usually able to account for it statistically.	Student develops and implements logical experimental procedures. Data are completely documented. Student is able to operate instrumentation and process equipment. Student analyzes and interprets data carefully using appropriate theory; if required, translates theory into practice or applies to process model(s). Student is aware of measurement error and is able to account for it statistically.	

Problem Solving	Student does not see the connection between theory and practical problem solving. Student has no concept of how to relate previous knowledge and new information. Student does not realize when major components of the problem are missing. Student has no coherent strategies for problem solving.	Student connects theoretical concepts to practical problem-solving with considerable prompting. With considerable assistance student can integrate previous knowledge and new information. Student seldom realizes when major components of the problem are missing. Student has few coherent strategies for problem solving.	Student connects theoretical concepts to practical problem-solving with some prompting. With some assistance student can integrate previous knowledge and new information. Student usually realizes when major components of the problem are missing. Student has strategies for problem-solving, but does not apply them consistently.	Student routinely relates theoretical concepts to practical problem solving. Student takes new information and effectively integrates it with previous knowledge. Demonstrates understanding of how various pieces of the problem relate to each other and the whole. Student regularly formulates and applies strategies for solving problems.	
Modern Tools	Student is incapable of using computer-based and other resources effectively within a research environment.	Student is seldom effective in using computer-based and other resources to complete research activities.	Student is usually effective in using computer-based and other resources to complete research activities.	Student is highly effective in using computer-based and other resources to complete research activities.	

Independent Learning	Student requires highly detailed or step-by-step instructions to complete a task. Student consistently repeats the same mistakes. Little or no awareness and/or use of external sources of information. Little or no initiative to explore new learning opportunities. Unwilling to take risks by undertaking challenging or unfamiliar assignments.	Student requires considerable guidance as to expected outcome of task or project. Student is sometimes able to avoid repeating the same mistakes. Some evidence of efforts to locate and use external resources. Some willingness to participate in learning activities and take risks. Some ability to use library/internet sources.	Student requires limited guidance as to expected outcome of task or project. Student is usually able to avoid repeating the same mistakes. Reasonable awareness and use of external resources. Reasonable willingness to participate in learning activities and take risks. Adequate ability to locate and use library and Internet resources.	Student demonstrates ability to complete tasks independently. Student learns from mistakes and practices continuous improvement. Fully aware of external sources of material. Effective use of supplementary resources. Actively seeks learning opportunities (reading, self-study, extra-curricular activities). Excellent ability to locate and use library and Internet resources.	
Safety	Safety procedures are ignored. Laboratory materials are treated carelessly. Student does not help with lab cleanup.	Experiments are seldom carried out with attention to relevant safety procedures. Laboratory materials are seldom cared for properly. Student provides little assistance with lab cleanup.	Experiments are usually carried out with attention to relevant safety procedures. Laboratory materials are usually cared for properly. Student generally assists with lab clean-up.	Experiments are carried out with full attention to relevant safety procedures. Laboratory materials are cared for properly. Student always assists with lab clean-up.	

Teamwork	Student promotes an atmosphere that is competitive and individualistic, ignores ideas from other group members, and claims the work of others as his/her own. Student does not understand their role within the group and cannot explain the roles of any group members. Student does not share responsibilities with others.	Student seldom treats group members with respect, listens to ideas from a few group members only, and rarely acknowledges the work of others. Student seldom understands their role within the group and can explain the roles of some group members. Student rarely shares responsibilities with others.	Student treats most group members with respect, listens to ideas from most group members, and usually acknowledges the work of others. Student generally understands their role within the group and can explain the roles of most group members. Student usually shares responsibilities with others.	Student treats other group members with respect, listens to ideas from all group members, and acknowledges the work of others. Student understands their role within the group and can explain the roles of all other group members. Student shares responsibilities equally with others.	
Professionalism	Student blames others for his/her own issues and problems. Student is frequently absent from group activities and is generally not collegial to fellow students, staff, and faculty. Student has been caught cheating or plagiarizing the work of others.	Student does not recognize the need to take personal responsibility for his/her actions. Student sometimes exhibits unprofessional behavior; is sometimes absent from group activities without reason. Does not model ethical behavior among peers and faculty.	Student usually takes personal responsibility for his/her actions. Student is generally punctual, professional, and collegial. Student usually demonstrates ethical behavior among peers and faculty.	Student always takes personal responsibility for his/her actions. Student is punctual, professional, and collegial. Student demonstrates ethical behavior among peers and faculty.	

Communication	Student is unable to summarize thoughts, ideas, and results clearly. Student fails to listen and respond, and provides no or discouraging and destructive feedback.	Student is seldom able to summarize thoughts, ideas and results clearly. Student seldom uses listening and responding skills which are facilitative, providing little encouragement and feedback.	Student is usually able to summarize thoughts, ideas and results clearly. Student usually uses listening and responding skills which are facilitative, providing some encouragement and feedback.	Student is always able to summarize thoughts, ideas and results clearly. Student uses active listening and responding skills which are highly facilitative, providing encouragement and constructive feedback.	
Knowledge of Contemporary Issues	Student has zero knowledge of current events, trends, initiatives, common goals, concerns, and activities within the group's area of research.	Student has little knowledge of current events, trends, initiatives, common goals, concerns, and activities within the group's area of research.	Student has knowledge of current events, trends, initiatives, common goals, concerns, and activities within the group's area of research.	Student has considerable knowledge of current events, trends, initiatives, common goals, concerns, and activities within the group's area of research.	
Societal Impact	Student has zero perspective on the importance of and broader impact of the group's research activities in today's world.	Student has little perspective on the importance of and broader impact of the group's research activities in today's world.	Student has perspective on the importance of and broader impact of the group's research activities in today's world.	Student has considerable perspective on the importance of and broader impact of the group's research activities in today's world.	

Appendix B

Undergraduate research oral presentation rubric

* Indicates required question

Your name *

Your answer

Presenter name *

Your answer

Select which of the following are true about the presentation **content** *

- [ ] Introduced motivation and interest in the topic
- [ ] Gave background/overview and identified key points early in talk
- [ ] Material was understandable and organized in a logical, coherent way
- [ ] Supported discussion of key points with sufficient evidence and detail
- [ ] Presented significant results supported by the data and analysis
- [ ] Concluded with concise and relevant remarks

Select which of the following are true about the presentation **delivery** *

- [ ] Looked at audience and did not read directly from notes or screen
- [ ] Spoke loudly enough to be heard in the room
- [ ] Appeared confident and enthusiastic

Select which of the following are true about the presentation **visuals** *

- [ ] Used the assertion-evidence approach to slide style
- [ ] Appropriate number of words and items on slides (not overloaded)
- [ ] Used font sizes/images that could be seen easily
- [ ] Diagrams were helpful for understanding
- [ ] Colors and designs enhances the diagrams and/or text
- [ ] Images suited purpose and content of presentation

Additional comments for presenter (optional)

Your answer

Select which of the following are true about the presentation **Question & Answer period**

- [ ] Listened to the question without interrupting
- [ ] Repeated or rephrased the question
- [ ] Addressed the answer to everyone
- [ ] Answered the question as clearly and succinctly as possible or stated honestly "I don't know"

Submit   Clear form