WIP: Project-Based Learning and Industry Engagement in an Introductory Polymer Science Course

Dr. Erick S. Vasquez-Guardado, University of Dayton

Erick S. Vasquez-Guardado is an Associate Professor in the Department of Chemical and Materials Engineering at the University of Dayton. Dr. Vasquez earned his B.Sc. degree in chemical engineering (ChE) at Universidad Centroamericana Jose Simeon Canas (UCA) in El Salvador, an M.S. in ChE at Clemson University, and a Ph.D. in ChE at Mississippi State University.

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A persistent challenge in engineering education is helping students connect foundational polymer science concepts to modern research literature and industrial practice. This paper reports the design, implementation, and initial evaluation of a sequenced project-based learning (PBL) framework integrated into an upper-level Introduction to Polymer Science – Thermoplastics course (n = 16). The instructional model combined three individual, literature-driven projects with professional engagement through invited guest speakers to strengthen student competencies in polymer chemistry, polymer properties, research literacy, and scientific communication. The project sequence was scaffolded from foundational to advanced content: (1) a thermoplastics case study requiring students to synthesize structure–property–processing relationships from a selected handbook chapter into an executive summary and presentation; (2) a polymer chemistry investigation of reversible-deactivation radical polymerization (RDRP) in which students compared ATRP, RAFT, and NMP mechanisms and analyzed a peer-reviewed application paper; and (3) a critical synthesis assignment in which students selected a recent high-impact review article from *Progress in Polymer Science* and integrated at least one additional supporting peer-reviewed source into a structured report addressing motivation, background, state-of-the-art, applications, conclusions, and future directions. Two polymer scientists from different institutions delivered guest lectures that further bridged classroom content with real-world research and manufacturing, followed by student-written summaries and reflections. Course outcomes were evaluated using project performance and a post-course survey containing Likert-scale items and open-ended responses. Overall, student performance on the projects was strong, and survey averages were generally at or above the "Agree" level, indicating positive perceived impacts on learning, engagement with literature, and communication skills. Qualitative feedback highlighted increased awareness of polymer diversity, improved confidence interpreting scholarly sources, and stronger perceived relevance of polymer science to contemporary engineering challenges. Opportunities for refinement were also identified, including the need for clearer rubrics, additional in-class reinforcement of advanced concepts (particularly for RDRP), and scope adjustments to support synthesis in the most open-ended project. These preliminary findings suggest that scaffolded, literature-based PBL assignments combined with professional engagement can enhance learning and motivation in introductory polymer science courses while maintaining technical rigor.

1. Introduction and Background

Project-based learning (PBL) is a student-centered, constructivist approach in which students develop knowledge and skills by working over a given period of time to investigate and respond to an authentic, meaningful problem, case study, or challenge. Learning in PBL is situated in context, driven by active inquiry and creation, and strengthened through collaboration, dialogue, and shared meaning-making, with the instructor serving as a facilitator who supports students' progress and understanding rather than simply delivering content through traditional lectures.[1], [2], [3]

A few examples of successful PBL implementations in Materials Engineering are available in the literature. For example, Chen et al. described the development of a project-based curriculum in Materials Engineering, where traditional lecture and laboratory activities were redesigned into open-ended projects that promoted professional skills, contextual learning, and student ownership of the learning process.[4] In addition, Harding et al. reported converting traditional materials laboratory experiments into project-based learning experiences, placing students in the role of designers and problem-solvers while faculty acted as coaches. Their work emphasizes that restructuring labs into PBL formats can better support the development of higher-order cognitive skills, including self-directed learning and design thinking.[5], [6] In an introductory Materials Science and Engineering course, the PBL component represented a substantial portion of the overall course assessment, with students completing a multidisciplinary design-and-build project as part of their grade, while exams were still used to evaluate core theoretical understanding.[7] To our knowledge, however, these implementations remain scarce in Introductory Polymer Science and Engineering courses.

In this study, students in an upper-level Introductory Polymer Science and Engineering course were assigned a series of sequenced literature-review-based, PBL-integrated assignments designed to strengthen their competencies in polymer science and engineering. Specifically, the PBL topics included polymer chemistry, polymer properties, and the characterization of a thermoplastic, as well as the study of an influential review paper from the journal *Progress in Polymer Science*. Note that no laboratory practices were part of the PBL implementations in this study. Additionally, technical communication was encouraged through the preparation of technical reports or presentations. To reinforce the relevance of polymer science beyond the classroom, two guest speakers representing different institutions shared examples of ongoing polymer research and its translation into industrial applications.

2. Course Description and Objectives

The Course: Introduction to Polymer Science – Thermoplastics was used for PBL project integration. The objective of this course is to provide a broad survey of polymer science and engineering, primarily as they relate to synthetic, organic thermoplastic polymers. The course covers a wide range of knowledge, mostly from basic polymer science and theory. The subject matter pulls broadly from interdisciplinary areas such as organic and physical chemistry, kinetics, material properties, and rheology. A major goal of the course is to provide the student with a well-rounded background to take further graduate courses in polymer science, or to work a chemical/process engineering position involving thermoplastic polymers in an industrial, academic, or government research and/or manufacturing environment. A list of the topics given to the students and dates presented for a traditional Fall semester are shown in Table 1.

Table 1. Topics and Schedule of Lectures for the Course

Date	**Topic / Activity**
Aug. 26	Syllabus, #1 Introduction
Sep. 2	#2 Polymerization I (STEP mechanism)
Sep. 9	#2 Polymerization II (ADDITION mechanism)
Sep. 16	#3 Polymer Properties and Testing
Sep. 23	#4 Molecular Weight Measurement
Sep. 30	#4 Molecular Weight Measurement
Oct. 7	NO class
Oct. 14	**Midterm Exam (sections 1-4), 5:05-7:45 p.m.**
Oct. 21	#5 Polymer Structure and Transitions
Oct. 28	#5 cont.
Nov. 4	#6 Polymer Viscoelasticity
Nov. 11	#6 cont.
Nov. 18	#7 Rheology and Flow
Nov. 25	#8 Polymer Processing
Dec. 2	#8 cont., SFT
Dec. 9	**Final Exam, 4:30-6:20 p.m.**

3. Course Structure and Grading

The PBL case studies complemented the course assignments/projects grade (45%), while traditional exams were also used to assess students' technical knowledge (55%). Each PBL assignment accounted for ~8% of the course grade (out of 100%). For each technical presentation (invited speakers), a short multiple-choice quiz was developed, which accounted for ~1.5% of the total grade. The total grade distribution for the course is presented in Table 2.

Table 2. Grade distribution for Introduction to Polymer Science – Thermoplastics course

Category	**Weight**
45%	Assignments (Literature Searches, Presentations, **PBL projects**, Excel spreadsheets - collected through Canvas)
25%	Midterm Exam (in class, closed book)
30%	Final Exam (in class, closed book)

4. PBL Assignments

The ultimate goal of the PBL assignments was to promote self-directed learning of broader topics in the field of polymer science and engineering. The Engineering librarian at the University of Dayton provided a library guide, a presentation, and several resources to the students to conduct literature reviews during the semester. A description of each of the three assignments is summarized next.

PBL Case Study 1: Study of a Particular Polymer. This assignment required each student to independently lead a focused study of a thermoplastic by selecting a unique chapter from the *Handbook of Thermoplastics*[8] and registering their choice to prevent overlap of polymers (e.g., polyacrylonitrile was chosen by only one student). Each student then expanded beyond the textbook by using additional credible sources (such as peer-reviewed articles, books, lectures, or technical media) to deepen understanding. The final deliverables include a 10-minute individual pre-recorded presentation communicating the most important polymer concepts and applications, along with a 2-page executive summary that synthesizes key findings (with optional appendices and encouraged references). Throughout the work, students had to properly cite all sources using citations in a specified format.

PBL Case Study II: Polymer Chemistry. This assignment required students to investigate controlled radical polymerization, formally referred to as reversible-deactivation radical polymerization (RDRP), through a structured research-driven activity. Students first conducted background research using scholarly library sources to summarize the key concepts and major RDRP methods—ATRP, RAFT, and NMP—in a concise written section. They then selected and analyzed a peer-reviewed journal article that connected RDRP to a topic of personal interest, encouraging students to link polymerization concepts to emerging applications and current research. The final deliverable consisted of a 6–7 page executive summary synthesizing both components, supported by figures where appropriate and documented using proper citations to demonstrate professional technical writing and academic research practices.

PBL Case Study III: Analysis of an Influential Review Paper. This assignment required students to conduct a critical, research-driven investigation of an advanced topic in polymer science by selecting a recent article (preferably from the past 4–5 years) from Progress in Polymer Science. In addition to evaluating the chosen paper, students identified at least one supporting peer-reviewed journal article that aligned with their personal interests and strengthened the technical depth of their analysis. Students then prepared a structured report of up to 12 pages that synthesized their findings and was organized into sections covering the motivation for topic selection, background and state-of-the-art developments, current applications, conclusions, and perspectives on future research directions. Figures were incorporated where appropriate to support key insights, and all sources were properly documented using citations

5. Students and Participants

This course is not mandatory in the program, but rather an elective course. The deployment of PBL activities was done with only 16 students. All the PBL assignments were completed individually. For classes with large enrollment of students, PBL group assignments could be given.

6. Survey Instruments to Assess Case Studies

To determine the effectiveness of each PBL assignment, a survey instrument was developed and administered after the final exam to ensure complete participation (For future implementations, each survey will be deployed separately after each activity). A traditional Likert scale (1 = Strongly Disagree and 5 = Strongly Agree) was used for student responses. To properly identify the questions, A1, B1, C1, etc. will be used for case study I questions, and subsequently for each case study. For the guest speakers A4, B4, etc. will be used. In addition, a few open-ended questions were provided to the students. Survey questions for each PBL assignment are shown below.

<u>Case Study 1: Survey Questions – Thermoplastics Book Chapter Review</u>

A. Case Study 1 improved my understanding of thermoplastics and their processing.
B. The structure–property relationships in my selected chapter became clearer through this assignment.
C. Preparing an oral video presentation improved my technical communication skills.
D. Hearing other students' presentations and preparing a paragraph summary broadened my understanding of thermoplastics.
E. Choosing my own chapter increased my engagement with the material.
F. The workload for Case Study I was appropriate for the learning outcomes.

Open-ended question:

- What was the biggest takeaway from the Thermoplastics assignment? (1–3 sentences)

<u>Case Study II: Survey Questions – Controlled Radical Polymerization</u>

A. Case Study II deepened my understanding of polymerization beyond step-growth and chain polymerization.
B. Reading primary literature on ATRP, RAFT, and NMP improved my conceptual grasp of CRP mechanisms.

C. I can explain key differences among ATRP, RAFT, and NMP after completing this project.
D. Connecting CRP methods to advanced materials applications helped me see their real-world relevance.
E. Writing the 6–7 page executive summary strengthened my scientific writing skills.
F. The expectation to integrate experimental and peer-reviewed articles improved my research literacy.
G. The workload for case study II was appropriate for the learning outcomes

Open-ended question:

- What part of Case Study II most supported your learning? (short answer)

Case Study III: Survey Questions – Review of *Progress in Polymer Science* Paper

A. Project III strengthened my ability to critically read a high-impact polymer science paper.
B. Selecting my own article increased my motivation and ownership of the project.
C. I felt prepared to choose an appropriate paper from Progress in Polymer Science.
D. This project helped me better understand the "state-of-the-art" in a modern polymer research area.
E. Identifying and reading an additional supporting peer-reviewed paper deepened my understanding of the topic.
F. I improved at connecting ideas across multiple research articles.
G. I gained a clearer understanding of applications and real-world relevance for the topic I studied.
H. Writing the 12-page synthesis report improved my scientific writing and organization skills.
I. The required report sections (motivation, background, state-of-the-art, applications, conclusions, future directions) helped structure my learning effectively.____
J. Developing "perspectives and future directions" improved my ability to think like a researcher.
K. I feel more capable of independently learning a new polymer topic through literature review.

Open-ended questions:

- What was the most challenging part of PBL III (e.g., article selection, understanding methods, synthesizing sources, writing future directions)?

- How do you see the knowledge from your Project 3 topic applying to real engineering or research problems?

Additional questions were used to assess the *technical presentations* by the guest speakers invited to the course lectures. These questions are shown below:

A. The guest lectures helped bridge theory and real-world polymer science.

B. I gained insight into current trends/challenges in polymer research and industry.
C. The guest speakers made polymer science feel more relevant to careers.
D. Interactive discussions during guest talks improved my understanding.
E. The short quizzes helped me reflect on and retain the guest lecture content.
F. Having speakers from different institutions broadened my perspective.
G. The number of guest lectures was appropriate for the course.
H. I would like more professional/research guest engagement in similar courses

Note: Student responses for all these questions were 4 or 5, and hence no further discussion is presented in the article. The students' engagement and interest in learning about polymer concepts outside the classroom were very beneficial to them.

Further, a few open-ended questions were given to the students, and these are listed below:

- Which assignment or course element most improved your learning, and why?
- Describe one key concept or skill you will take from this course into future work.
- What was the most challenging part of the course, and how could it be supported better?
- Any additional feedback on course structure or assignments?

7. Results and Discussion

7.1 Student Performance in the PBL Assignments

First, an overview of the grade distribution for the PBL assignments is presented. Most students performed well on the projects, and overall scores were relatively high, as shown in Figures 1–3. For future course offerings, more formal grading rubrics will be developed for each PBL component and shared with students in advance. The absence of detailed rubrics is acknowledged as a limitation of the current study.

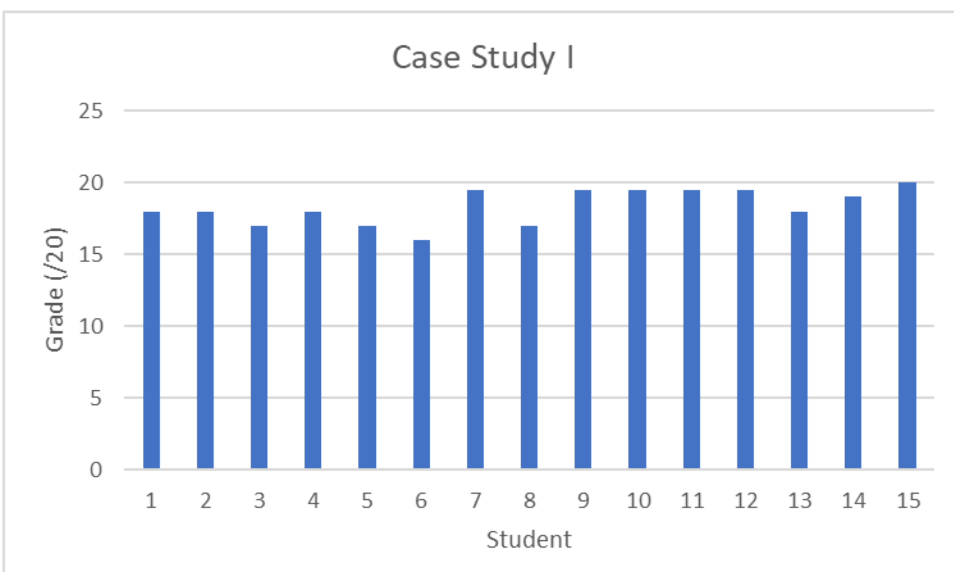

Figure 1. PBL Grades for Case Study I - Thermoplastics Book Chapter Review

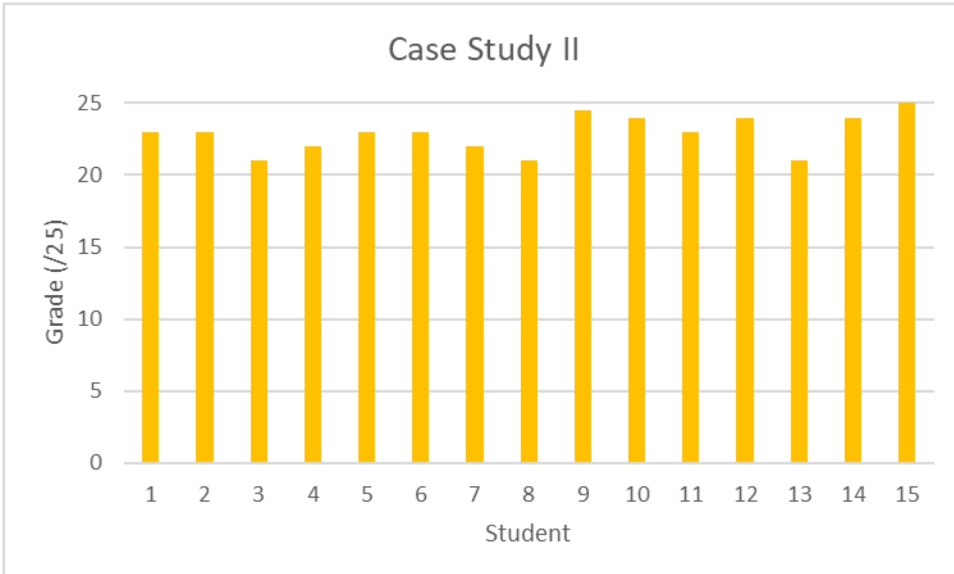

Figure 2. PBL Grades for Case Study II - Controlled Radical Polymerization

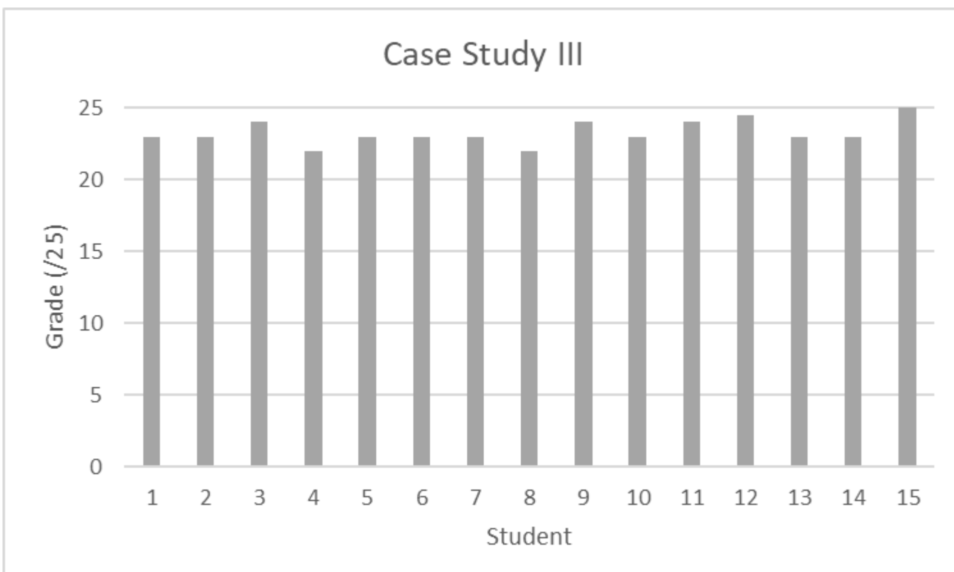

Figure 3. PBL Grades for Case Study III – Review of Progress in Polymer Science Paper

7.2 Student Overall Performance on the Course

Overall, performance on the midterm and final exams played a major role in determining students' final course grades. Although most students earned an A or A− on the PBL assignments, some struggled on the exams and ultimately finished the course with a C. This outcome highlights the importance of carefully balancing the grade allocation between project-based components and traditional assessments. In this course, the PBL activities accounted for approximately one-third of the total grade. Final course grade distributions are shown in Fig. 4.

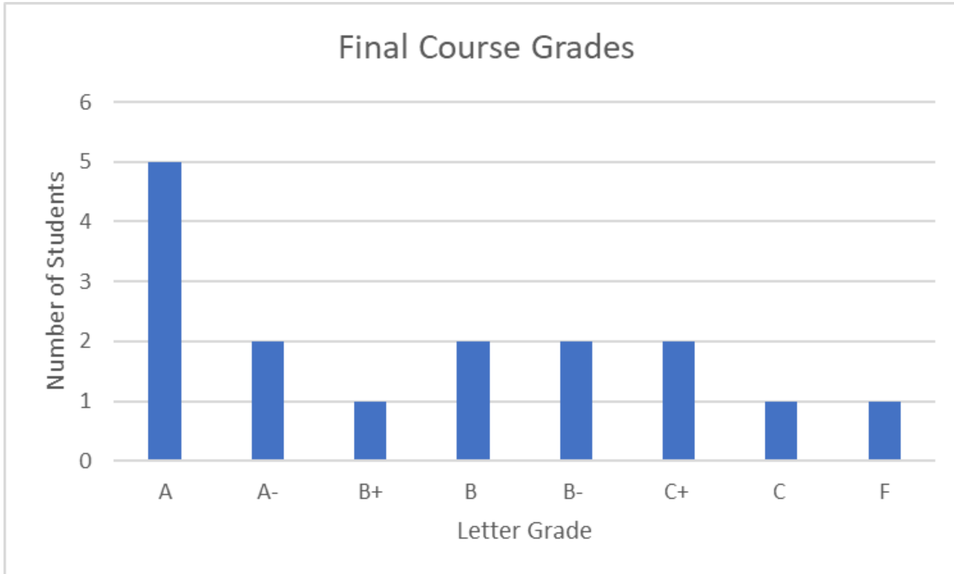

Figure 4. Final Course Grade Assignment in "Introduction to Polymer Science - Thermoplastics"

7.3 Numerical Responses of Survey Questions.

For the three case studies, the majority of the average results were 4 or above (Agree/Strongly Agree). Results that were below the 4-point mark are discussed.

7.3.1. Case Study I – Survey Questions and open-ended responses.

The only question that had an overall value below 4 was question D1: "*Hearing other students' presentations and preparing a paragraph summary broadened my understanding of thermoplastics*." The average response for this question was 3.7. It is believed the lower score was given because this activity involved pre-recorded presentations rather than in-person presentations. Most of the students would have preferred in-class presentations, and future courses will follow this practice.

Results of the open question: "*What was the biggest takeaway from the Thermoplastics assignment?*" revealed some interesting learning outcomes/aspects that complement the course objectives well. A few quotes are listed below directly from the surveys:

> *"Thermoplastics are in progress to match high performance [thermal + mechanical] of thermosets."*
>
> *"Biggest takeaway was just how many thermoplastics there are, and the growing need across various industries. Really liked selecting my own chapter, improved my interest."*
>
> *"I have a clear idea to consider multiple polymer materials."*
>
> *"My topic of advanced thermoplastics enabled me to understand the topic more deeply."*

7.3.2. Case Study II - Survey Questions and open-ended responses.

For the PBL case study II, controlled radical polymerization, four different questions had a score below 4. These were the following questions:

C2. I can explain key differences among ATRP, RAFT, and NMP after completing this project (3.71/5).
D2. Connecting CRP methods to advanced materials applications helped me see their real-world relevance (3.86/5).
E2. Writing the 6–7 page executive summary strengthened my scientific writing skills (3.86/5).
G2. The workload for case study II was appropriate for the learning outcomes (3.86/5).

It is interesting to note that these questions were below the Agree/Strongly Agree mark, as these were directly related to the learning outcomes. It is possible that the topic is too advanced and that it should be covered in regular lectures. However, due to the limited number of current responses it is something worth investigating in future course deliveries.

For the open question, "*What part of Case Study II most supported your learning?*," some quotes are listed below:

> *"Helped advance my understanding of polymerization from previous lectures."*
> *"to research made it easier to learn, but was tedious."*
> *"I liked the structure outline provided and the ability to research."*
> *"Self learning combined with professor's teaching is great."*

Overall, the comments were mostly positive. For future courses, the concepts should be reinforced in the classroom through lecture notes.

7.3.3. Case Study III - Survey Questions and open-ended responses.

For the PBL case study III, review of a paper in *Progress in Polymer Science*, more questions were evaluated. Of the 11 questions, only 4 had scores below 4. The following questions were rated, on average, below Agree/Strongly Agree:

A3. Project III strengthened my ability to critically read a high-impact polymer science paper (3.86/5).
E3. Identifying and reading an additional supporting peer-reviewed paper deepened my understanding of the topic (3.64/5).
H3. Writing the 12-page synthesis report improved my scientific writing and organization skills (3.64/5).
J3. Developing "perspectives and future directions" improved my ability to think like a researcher (3.79/5).

Although the scores were below 4 for these questions, it is worth noting that the addition of other papers to the selected article (QE3) did not yield good results. Perhaps, a more comprehensive evaluation on a single review article should be provided to the students. The length of the analysis (12 pages) was perhaps too long. Synthesizing the information was a struggle for the

majority of the students. Note that a section on perspective and future directions was requested; however, these did not receive positive feedback either.
Results for open questions for PBL case study III are noted below

"What was the most challenging part of PBL III (e.g., article selection, understanding methods, synthesizing sources, writing future directions)?"

> *"Understanding the underlying chemistry of the research, given I have a limited background."*
> *"Organizing the key points of the article."*
> *" looking for a research article within the time span of 4 – 5 years."*
> *"….challenging to select another appropriate article to go along with my topic that was also relatively new."*
> *"Synthesizing sources and across such a big document."*

"How do you see the knowledge from your Project 3 topic applying to real engineering or research problems?"

> *" I can see my topic being applied to a variety of industries to improve sustainability."*
> *" Mitigating environmental pollution."*
> *"Apply my knowledge on the results procured from the research articles and choose my materials correctly."*
> *"Replacing toxic materials with polymers, which is important for clinical safety in the future."*

Overall, most students found value in the papers they read and in how their interest in polymers aligned with a specific application or setting (e.g., environmental). The constraint on the latest published articles can be removed for future courses.

7.3.4 Industry talks – open-ended question responses.

For the open question "What did you find most valuable about guest lecturers (industry talks)?", some of the student answers were:

> *"Getting a glimpse into the industry outside the classroom setting."*
> *" Their experience in the polymer field"*
> *" It showed me that companies are involved with polymer science concepts and how it is applied into an industrial setting"*
> *"Getting to see real examples of careers that involve working with polymers."*

Lastly, rubrics and all related assessment materials, including assignments and examinations, are available upon request.

8. Summary and Conclusions

This study presented the implementation of a sequenced set of project-based learning (PBL) assignments and industry engagement activities in an upper-level Introduction to Polymer Science – Thermoplastics course. Three research-integrated, individual case studies were designed to help students develop deeper competency in polymer chemistry, polymer properties, and modern polymer technologies while strengthening scientific communication skills. Case Study I reinforced foundational knowledge through an independent thermoplastics chapter review and student presentations. Case Study II expanded polymer chemistry learning beyond step-growth and chain polymerization by requiring students to investigate reversible-deactivation radical polymerization (RDRP) methods and connect them to peer-reviewed applications. Case Study III promoted research literacy by guiding students through a critical synthesis of a high-impact Progress in Polymer Science review paper and related supporting literature. Additionally, two guest speakers provided professional context and strengthened the connection between course theory and real-world polymer research and manufacturing.

Overall, students performed strongly on the PBL deliverables, and survey results indicated generally positive perceptions of the learning benefits of these activities, with most Likert-scale averages at or above the "Agree" level. Student comments highlighted gains in self-directed learning, technical writing, and appreciation for the breadth and relevance of polymers across industries. However, several survey items in Case Studies II and III fell below an average of 4.0, suggesting that students experienced challenges in synthesizing advanced literature, distinguishing mechanisms across polymerization methods, and developing future directions like a researcher. These results are consistent with prior findings that PBL can effectively bridge theory and practice, but that students may require structured scaffolding, periodic feedback, and explicit support to successfully manage complex and open-ended research tasks.

In summary, the course design demonstrated that literature-based PBL assignments paired with industry engagement can enhance student learning in an introductory polymer science setting by increasing conceptual understanding, building research literacy, and reinforcing professional communication skills. Future deliveries of the course will incorporate improvements such as clearer grading rubrics, additional in-class reinforcement of advanced topics (especially RDRP), proper use of artificial intelligence (AI), and revised project scope to reduce cognitive overload (e.g., shortening the Project III report length or limiting required supporting articles). Expanding participation across additional semesters and comparing outcomes across cohorts will strengthen the evidence base for the impact of this instructional approach on student achievement and long-term confidence in independent learning of polymer science topics.

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