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Reacting with Nature: A Community-Based Project in Sustainable Water Reuse for Undergraduate Engineering Education

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Introduction

Engineering educators have the important duty of preparing students to address complex international sustainability challenges, including climate change, infrastructure development, and access to clean water [1, 2]. Meeting these challenges will require not only technical theory, but also applied professional competencies, such as the ability to navigate uncertainty, engage with diverse stakeholders, and iteratively define problems in real-world contexts [3, 4]. One approach engineering educators have used to develop students' applied knowledge is through project-base learning, however gaps in its curricular implementation remain.

While projects are an effective way to develop applied engineering skills, the majority of engineering course projects occur in isolated modules in the first-year or in capstone courses, with few mid-curriculum projects [5]. Additionally, many projects remain decontextualized from local communities, limiting students' opportunities to connect technical analysis with proximal societal impact [6]. Meaningful partnerships between engineering courses and community organizations are relatively rare, particularly in technically intensive mid-curriculum courses where content coverage pressures are high.

These and other curricular gaps were pronounced in Carnegie Mellon University's chemical reaction engineering course. This course is usually taught in the third year of the undergraduate chemical engineering degree, and emphasizes mathematical modeling, numerical analysis, and reactor design under idealized assumptions. While these skills are foundational, students in the course often struggled to connect abstract models to physical systems. Faculty observations and student feedback highlighted that students were exiting the course with a lack of physical intuition of how reactors operate or understanding of the complexity of gathering real data for modelling. The instructor decided to develop a community-based project for the course based on prior research which has shown their effectiveness in developing students' physical intuition and applied knowledge.

This paper describes the development and implementation of a semester-long, sustainability-focused, community-based project embedded within a third-year undergraduate reaction engineering course. The project was developed in partnership withPhipps Conservatory and Botanical Gardens' Center for Sustainable Landscapes (CSL), a local nonprofit organization operating a constructed wetland and lagoon system for on-site water reuse. Through this partnership, students applied chemical reaction engineering principles to model pollutant removal processes in real water treatment systems, using operational data and literature-based parameters to explore seasonal and system-level complexity. The sustainability focus allowed for the project to highlight nontraditional applications of chemical engineering.

While this is not a research paper, this work also used project evaluation techniques to examine the project's impact on students and instructional staff. Data for project evaluation included student course evaluations and reflections from the instructor and course assistants (CAs). Unlike studies aimed at generating generalizable learning knowledge, this paper adopts a practice-oriented lens, focusing on how community-engaged, sustainability-centered projects may be implemented within technically intensive courses. The paper also highlights the role of student CAs—particularly former students—in supporting community partnerships, curriculum development, and iterative project refinement.

By documenting both the pedagogical approach and lessons learned, this work offers practical guidance for engineering educators seeking to integrate real-world sustainability challenges into mid-curriculum chemical and environmental engineering courses. The following section provides background on the course context, community partner, and learning objectives that shaped the project's design.

Background

I. Course Background

The Reacting with Nature project was introduced in a Chemical Reactions Engineering (CRE) course at a small, private, R1 institution in the northeastern U.S. CRE, offered each Spring (≈45–55 students), primarily enrolls third-year undergraduates, reflecting the institution's broader demographics, with Hispanic/Latino and BIPOC groups underrepresented.

CRE meets for three 1 hour and 20 minute lectures weekly. The course has no recitations or lab sections, and previously had no projects or group work. The course typically included 3 in-class exams, 10 homeworks, and daily in-class active learning exercises. The key learning outcomes for the course are to develop skills in mathematical modeling, numerical analysis, and coding for reactor analysis and design.

II. Researcher Positionality

This section outlines the researchers' backgrounds to acknowledge how their perspectives shaped the project's design and this paper's conclusions.

The first author is well-acquainted with the CRE course as he completed a Bachelor's degree in Chemical Engineering at the institution of focus and served as a peer tutor for the course. He worked closely with the second author on previous research projects, and had developed rapport with her prior to starting as a Project Course Assistant (CA). This familiarity offered valuable insights into the course experience for project development and implementation, but also introduced potential bias, as his experiences and aspirations for the project may have influenced the project evaluation process. The first author entered the project excited to gain curriculum development experience, to work with the CSL, and to positively impact his chemical engineering community.

The second author has a bachelor's and master's degree in chemical engineering, and a doctoral degree in mechanical engineering. As an Associate Professor in the Department of Chemical Engineering and the course instructor for CRE, she helped develop the project, bringing an in-depth understanding of its objectives and implementation.

III. Learning Objectives

Based on the institutional and course needs discussed in the Introduction section, the following six learning objectives were developed for the project. By the end of the projects, students should be able to:

1. **Explain key processes in water recycling systems:** Students will explore technologies used in real-life water purification/filtration, specifically how chemical reactions are used in nature-based solutions.
2. **Model water purification using chemical reactor principles:** Teams will model different reactors (e.g., batch, CSTR, PFR) to simulate water purification stages.
3. **Apply analytical methods to reactor design problems:** By performing calculations and developing models, students will strengthen their understanding of reactor design and chemical engineering.
4. **Collaborate effectively to address engineering challenges:** Students will work in teams, improving their ability to collaborate and present their findings in various formats.
5. **Communicate technical results through multiple professional formats:** By the end of the project, students will effectively communicate their results through a poster, video, and technical planning documents.
6. **Critically evaluate and compare reactor model assumptions:** Students will learn to provide and receive constructive feedback on their work and evaluate the strengths and weaknesses of various models and assumptions.

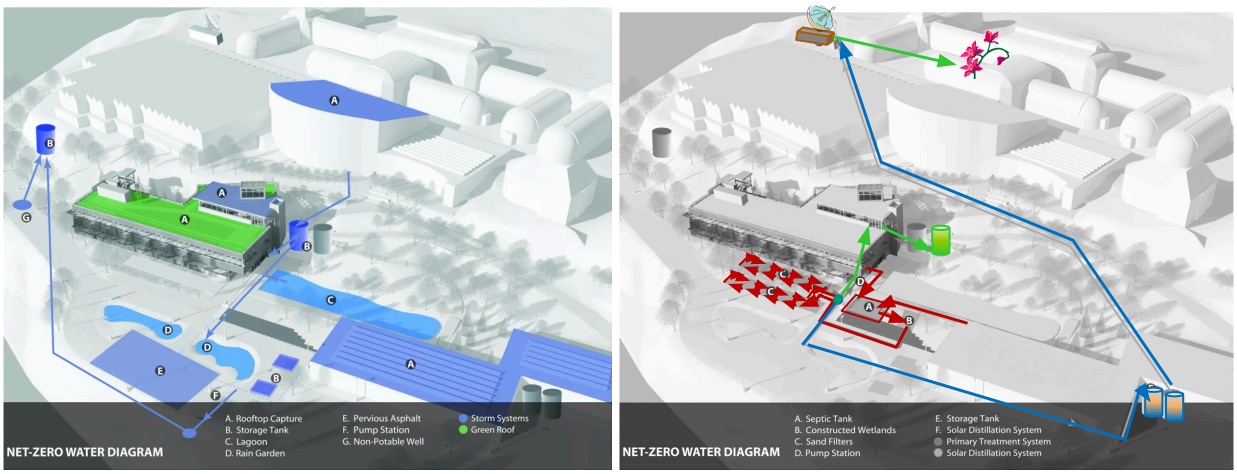
Note: These learning objectives were later modified to reflect best practices in learning objective writing as supported by the institution's center for teaching and learning.

In hindsight, there are additional learning outcomes that might have been important to include. Ideas for possible additional learning objectives include:developing design skills (e.g., iterative problem definition), proposing solutions without help from AI, critically evaluating the quality of AI-generated assistance, and providing, receiving, and implementing constructive feedback.

IV. Community Partner

The community partner for the Reacting with Nature project was the Phipps Conservatory and Botanical Gardens' CSL. This nonprofit organization is located next to the institution's campus where the course is being taught. The CSL is widely renowned for its emphasis on sustainable building design. The CSL operates as a "living building," integrating architectural, ecological, and engineering systems to minimize environmental impact while serving as a public demonstration and educational space.

Amongst its many sustainable design features, the CSL has impressive on-site water management and reuse systems for rainwater and wastewater, which are shown in Figure 1.



(A) (B)

Figure 1. Process diagram of the CSL's rainwater treatment system (A) wastewater treatment system (B).

All wastewater generated on site is treated using a combination of constructed wetlands, lagoons, sand filtration, and ultraviolet disinfection processes before reuse [7]. These treatment systems must operate under variable flow and seasonal conditions, making them well-suited for illustrating the modeling and operational complexity of real engineering systems. Unlike conventional municipal treatment plants, the CSL's systems rely heavily on nature-based solutions, providing a compelling context for exploring nontraditional applications of chemical reaction engineering principles.

To promote sustainable landscape design and practices, the CSL hosts a variety of educational activities including K–12 programs, public tours, professional workshops, and collaborations with local universities. Staff members from facilities management routinely engage with visitors to explain the design and operation of the CSL's systems. This educational experience made it a strong partner for a course-based project that sought to integrate technical modeling with communication to diverse audiences.

Project Design, Implementation, and Evaluation

I. Developing the Project Course Assistant Role

To support the design, implementation, and iteration of the community-based project, a Project CA role was co-created by the course instructor and a former student who had taken the course and served as a peer tutor for it. The Project CA role required approximately 10 hours per week beginning in Fall 2024. The role was different from traditional teaching assistant positions, focusing on project development, community partnership coordination, and student team support rather than normal grading or recitation instruction.

During the Fall 2024 semester, the Project CA focused on project scoping and preparation. Responsibilities included reviewing literature on engineering course projects and community-engaged learning, leading outreach to potential community partners, coordinating and attending meetings with prospective organizations, and assisting the instructor in selecting a partner aligned with course learning objectives. The Project CA also contributed to defining project learning objectives, drafting project documents, collecting and organizing operational data from the community partner, developing grading rubrics, and testing project prompts and calculations to ensure feasibility. Additionally, the Project CA coordinated logistics for site tours and planned the format and schedule for final student presentations. This preparatory phase was critical for ensuring that the project aligned with both pedagogical goals and partner needs prior to implementation.

In Spring 2025, the Project CA supported project implementation and student engagement. The Project CA attended class sessions to introduce the project and expectations. reviewed and provided feedback on all project deliverables, facilitated peer feedback, and met individually with student teams for advising throughout the semester. The role also included leading site tours at the partner facility and synthesizing peer evaluation feedback for the instructor using the FeedbackFruits Group Member Evaluation module in Canvas. Finally, the Project CA assisted with organizing and assessing the final poster presentation event, including coordinating logistics, setup, and teardown. Structuring the role around a former student provided several advantages: familiarity with course content and expectations, credibility with students, and the ability to anticipate common challenges. From an instructional perspective, this model allowed significant project support at a lower cost than a graduate TA while freeing instructor time for higher-level oversight. For instructors seeking to adopt similar community-based projects, we recommend clearly defining the scope of a project-focused assistant role early, prioritizing candidates with prior course experience, and allocating sufficient preparatory time to support sustainable implementation.

II. Forming a Community Partnership

In searching for a community partner to support our course project, we considered a number of factors including their responsiveness, willingness to offer access to their facilities, proximity to campus, and alignment of their systems with the project learning objectives. This section will explain each of these factors in more detail; we encourage instructors at other institutions to make a list of their priorities and needs prior to reaching out to potential community partners.

We initially reached out to multiple organizations including a bakery and multiple breweries, but the CSL was the most responsive and showed the most enthusiasm for collaboration. After some initial virtual correspondence, we set up in-person meetings to discuss logistics and tour the facilities.

Access to the partner's facilities was also important for the project's goals. We wanted students to conduct tours of the facility to develop a physical understanding of the reactor systems. The CSL had experience with providing tours to the public and was willing to host repeated tours for the students. Additionally, the CSL offered to host the final poster presentations in one of their event halls, which allowed students to present their work to diverse audiences. This setting reinforced the project's emphasis on sustainability, public engagement, and the societal relevance of reaction engineering. Additionally, the CSL's proximity to campus made in-person site visits more logistically and financially convenient.

We entered the partnership search eager to show off sustainable and non-traditional applications of chemical engineering. Not only did the CSL's facilities match this desire, but we also uncovered the organization's need to evaluate and improve aspects of its water reuse system in a way that aligned nicely with the course's learning objectives. While the facility continues to operate, staff expressed interest in better understanding pollutant removal mechanisms, seasonal performance variability, and potential design tradeoffs within the system. These open-ended questions allowed student teams to engage in engineering analysis while offering possible avenues of further exploration to the CSL. Students were encouraged to explore modeling assumptions, interpret literature data, and critically assess the limitations of simplified reactor representations. In addition to their presentations being great for learning, their analysis provided potentially valuable insights to the CSL team.

III. Project Implementation Details

The Reacting with Nature project was implemented across the spring semester and organized around four scaffolded milestones designed to support learning through an open-ended applied engineering problem (see Figure 2). The milestones emphasized iterative problem definition, technical modeling, and professional communication, with structured feedback and support throughout.

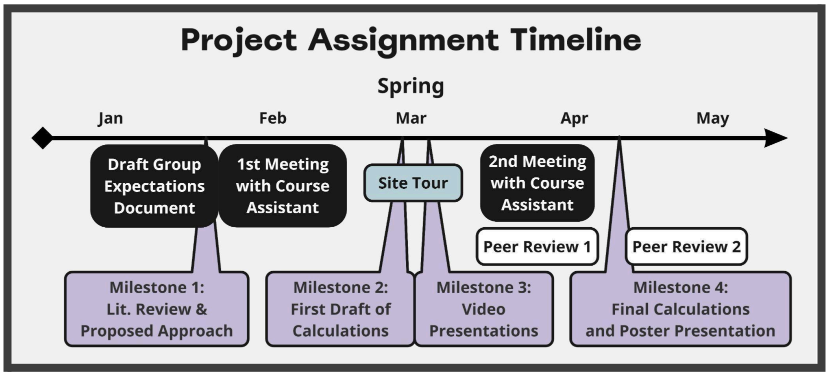


Figure 2. Timeline for project implementation.

The project began with team selection and drafting a Group Expectations Document. The project had twelve open-ended prompts; each of the twelve teams selected their prompt on a first-come-first-serve basis. These steps prepared them for milestone 1, in which student teams completed a literature review and proposed a modeling approach for a water treatment process relevant to their prompt. During this phase, teams met with the Project CA and received feedback to refine scope, clarify assumptions, and connect literature findings to course concepts.

Milestone 2 and 3 coincided, with milestone 2 encompassing a first draft of reactor models and calculations, and milestone 3 having teams create short technical video presentations for their drafted approach. Afterwards, they participated in structured peer review on the videos of all other teams. Around the same time, teams completed a guided site tour of the partner facility, allowing students to connect the physical system to their modeling approach and assumptions. Follow-up meetings with the Project CA helped with finalizing their parameter selections and key findings, and communicating limitations of their simplified model.

Milestone 4 emphasized information synthesis and communication. Teams first redrafted their work from previous milestones for their final posters, then received feedback for revision. Teams presented their revised posters in a public session hosted at the CSL. To encourage a diversity of attendance, the event was advertised widely through the college of engineering newsletter and through the university's sustainability center. Other engineering instructors offered their students extra credit for attending the event. Attendees were able to vote on awards given to two distinguished teams. A university marketing professional attended the event to write an article for the department and invited a professional photographer. This final milestone reinforced professional communication skills to both technical and non-technical audiences, with a focus on highlighting the societal relevance of chemical reaction engineering.

IV. Project Evaluation Data Collection

Although this paper does not present generalizable research, student feedback (i.e., a midsemester feedback form and end-of-semester Faculty Course Evaluations) and instructional reflections were collected for the purpose of iteratively improving the project and sharing its impact to other practitioners.

Student feedback was collected at two points in the Spring 2025, starting with a midsemester feedback form that was delivered as an in-class activity. This form included 10 mostly open-ended questions, with two that specifically asked about the course project (see Appendix I for the full midsemester feedback questionnaire). One project-related item used a Likert-scale format, for which the average score was reported. Responses to the open-ended project question were analyzed using reflexive thematic analysis (RTA) [8]. This analysis approach explicitly accounts for researcher positionality and reflexivity during interpretation of qualitative data. The analysis involved iterative familiarization with the data, inductive coding, and theme development, with consistent memoing in-between stages to document both observed patterns and the researcher's interpretation of why those patterns were salient to them.

For the end-of-semester Faculty Course Evaluations (FCEs), students responded to a total of 10 questions (see Appendix II for the full FCE questionnaire). Average Likert scores from the year prior to implementation (Spring 2024) were compared to those from the implementation year (Spring 2025) using Welch's t-tests. In addition, students were able to leave open-ended comments about any aspect of the course. These open responses were analyzed separately from the midsemester feedback using RTA, with coding focused on comments referencing the project and its perceived influence on learning, engagement, and workload.

Instructional reflections were collected in the Fall of 2025 from the Spring 2025 instructional staff including the course instructor, the project CA, and two undergraduate course CAs. These reflections were meant to elicit formalized strengths, challenges, and areas for improvement for the writing of this paper and improvement of subsequent iterations of the project (see Appendix III for the reflection prompt). These responses were coded separately from other qualitative data using RTA.

Results

I. Midsemester Feedback Form Results

From the midsemester feedback form, two project-related questions were analyzed for project evaluation:

1. On a scale from 1 to 5, how well do you think the Reacting with Nature course project is going so far?
2. What feedback do you have on the course project, the project instructor Gabe, and ways to improve the project for the second half of the semester and/or in future semesters?

For the first question, the average score across 41 respondents was 3.10, suggesting that students viewed the project as moderately successful at midsemester while seeing opportunities for improvement.

Qualitative analysis of the open-ended feedback yielded nine codes, whose prevalence is summarized in Figure 3. These codes were synthesized into three overarching themes, described below (see Appendix IV for the full codebook). Together, these themes highlight tensions between students' enjoyment of the project's applied, open-ended design and their desire for project clarity, scaffolding, and alignment with other instructional material.

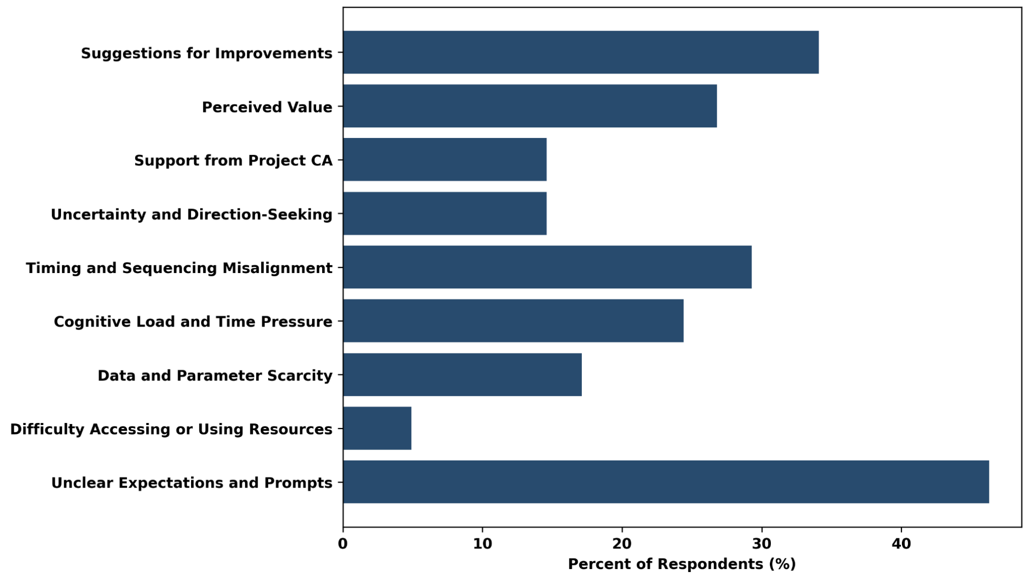


Figure 3. Prevalence of qualitative codes for midsemester feedback.

Theme 1: Navigating Ambiguity in an Open-Ended Project

Associated codes:

- Unclear Expectations and Prompts
- Uncertainty and Direction-Seeking
- Difficulty Accessing or Using Resources

Many students described difficulty interpreting project prompts, milestone expectations, and rubrics, particularly early in the semester. This ambiguity contributed to uncertainty about whether teams were "on the right track," especially when selecting reactor models, making assumptions, or determining appropriate levels of rigor. Several students also noted challenges locating or effectively using supporting materials, which exacerbated uncertainty. While ambiguity was intentionally incorporated to reflect real-world engineering practice, the feedback suggests that additional scaffolding—such as clearer prompt language, project examples, or more checkpoints—may help students productively engage with open-ended problem solving.

Theme 2: Structural Misalignment and Cognitive Load

Associated codes:

- Cognitive Load and Time Pressure
- Timing and Sequencing Misalignment
- Data and Parameter Scarcity

The second theme centered on the demanding nature of the project relative to course pacing and workload. Students frequently reported feeling overwhelmed by closely spaced milestones, concurrent homework and exams, and the need to develop models before relevant reactor concepts had been fully covered in class. These pressures were exacerbated by the difficulty of finding system-specific data and parameters in the literature, which many students found time-consuming and frustrating. Collectively, these responses point to a need for improved alignment between project timing, course content coverage, and expected scope of analysis.

Theme 3: Instructional Support and Perceived Value

Associated codes:

- Support from Project CA
- Perceived Value
- Suggestions for Improvements

Despite challenges, many students expressed strong appreciation for the project's real-world relevance and area of focus. Students frequently described the project as enjoyable, valuable, and important for future engineering practice, even when it was difficult. The Project CA was often cited as a key source of guidance and reassurance, helping teams navigate ambiguity and remain motivated. At the same time, students offered concrete suggestions for improving future iterations, including additional in-class work time, adjusted milestone spacing, clearer expectations, and refined project scope. This balance between frustration and perceived value is illustrated by one student's reflection:

> *"I really like how the project is grounded in a real-life, local scenario which makes it a lot more exciting. I'm finding the project to be challenging which, in the moment is sometimes frustrating especially when combing through literature to try to find specific values, but I know I'll really appreciate the experience in the end."*

II. Faculty Course Evaluation Results

Of the 10 questions in the FCEs, two were selected for analysis as the researchers felt they were the most closely connected to the desired outcomes of the project. For both questions, the average score showed no statistically significant change after implementing the project (i.e., between 2024 to 2025). The results are summarized in Table 2.

Table 2. Faculty Course Evaluations Likert averages between 2024 and 2025.

Question	2024 Average Score (N = 46)	2025 Average Score (N = 49)	Welch's T-Statistic
How would you rate the overall quality of the course?	3.83	3.76	0.369
Does the faculty member demonstrate the importance	4.11	4.02	0.500

and significance of the subject matter?	

Given the many course components and large variation in cohorts, the absence of significant changes in FCE scores does not indicate the project had no effect on the students. To better understand end-of-semester experiences of the course project, the open-ended student FCE comments were analyzed and compared to midsemester feedback. RTA of the 22 open-ended responses found seven codes, whose prevalence is summarized in Figure 4. These codes were synthesized into two overarching themes, one focusing on the project and the other on perceptions of the overall course (see Appendix V for the full codebook).

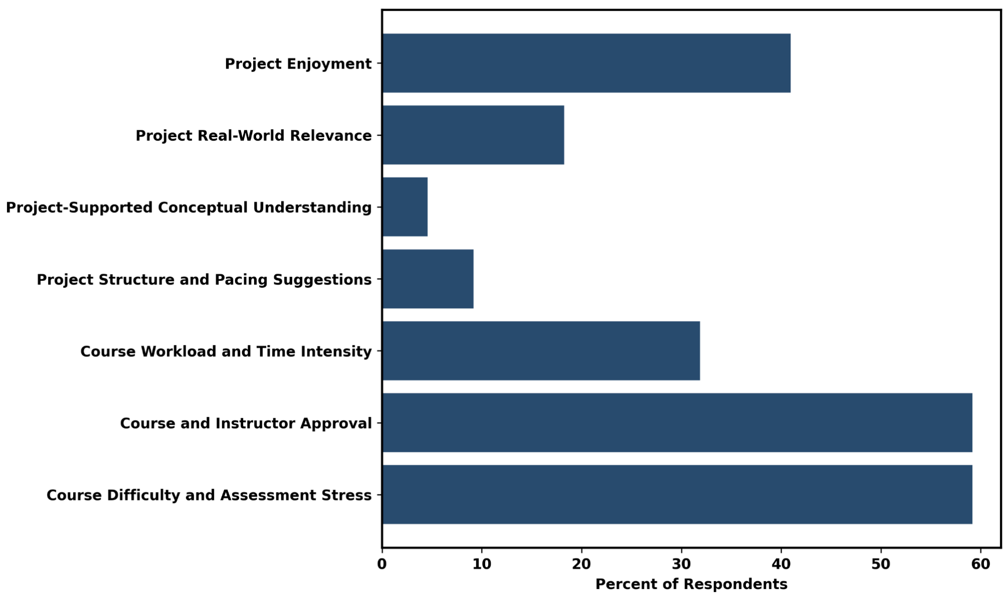


Figure 4. Prevalence of qualitative codes for midsemester feedback.

Theme 1: Perceived Value of Project

Associated codes:

- Project Enjoyment
- Project Real-World Relevance
- Project-Supported Conceptual Understanding
- Project Structure and Pacing Suggestions

Unlike the midsemester form, the open-ended FCE question did not explicitly ask about the project. Despite this, 10 of the 22 students brought up the project of their own accord. While the midsemester project feedback highlighted numerous areas of growth, all 10 end-of-semester responses which discussed the project were entirely positive, with some minor recommendations for scheduling improvement. Students found the project fun, engaging, and important for developing applied engineering skills, often citing it as a highlight of the class. They explicitly mentioned enjoying the final presentations at the CSL and getting to share their work to non-technical audiences. The following student quote highlights this engagement:

> *"The addition of the project for this semester was a great choice. I felt like it was a great way to take the content we learned from the course and apply it to the real-world context in an environmentally-focused engineering application and this was definitely a bright spot in the semester for me. I am hopeful that this will continue to be built out in the future so that other students can share this experience."*

Theme 2: Engagement and Challenges with Overall Course

Associated codes:

- Course Workload and Time Intensity
- Course and Instructor Approval
- Course Difficulty and Assessment Stress

Students found the course as a whole to be valuable and engaging, but many emphasized its challenging nature resulting from intentionally rigorous exams, many different course components, and heavy workload. Despite these challenges, many cited the instructor as a caring, responsive, and skilled teacher, and ended up enjoying the course by the end.

III. Instructional Reflection Results

The instructional staff as a whole observed students'resilience through their initial uncertainty with the course project, ultimately leading to excitement while developing engineering competencies important for future classes and their careers. The RTA process produced nine codes from the four instructional reflections; Figure 5 shows the distribution of these codes. These codes were constructed into three themes described below (see Appendix VI for the full codebook).

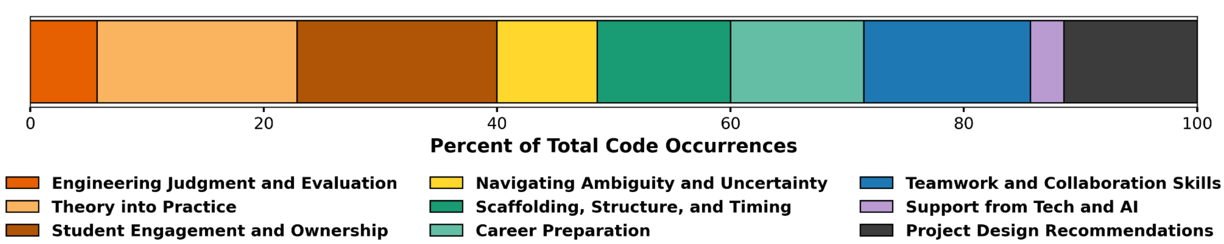


Figure 5. Distribution of qualitative codes for midsemester feedback.

Theme 1: Developing Engineering Skills through Application

Associated codes:

- Engineering Judgment and Evaluation

- Navigating Ambiguity and Uncertainty
- Student Engagement and Ownership

The instructional team discussed how the community-based project supported students' development of skills that were essential for further engineering studies and practice. While students were observed to initially struggle with the open-ended prompts, they gradually became more comfortable with constructing their unique approach, as shown by this quote:

> "I think they realized that uncertainty was not going to be punished, but rather treated as a part of the learning process. With ample opportunity for iteration and re-submission, the stress subsided with the project to some extent."

As the anxiety eased, students developed deeper critical reasoning and discernment skills through the literature review and justification of their modelling approach and assumptions. This was amplified by the students integrating their personal interests into their project design and milestone submissions; for example, one team created a stop-motion animation for their milestone 3 video to describe how their reactor worked. The class smiled and laughed as they engaged with this video. This highlighted both students' growing excitement for the project and their ownership of their work and reactor model.

Theme 2: Preparing Students for Engineering Careers

Associated codes:

- Career Preparation
- Teamwork and Collaboration Skills
- Theory into Practice

The instructional team also highlighted how the project helped prepare students for future careers. This included connecting theoretical course content to engineering practice, cultivating teamwork and collaboration skills, and offering applied engineering experiences that students used for LinkedIn posts, their resumes, and job interviews. The instructional team observed excitement, smiles, and energetic presentations at the final symposium at the CSL. Many students expressed their enjoyment of the event and project both verbally to the CAs and through their LinkedIn posts. As a whole students reported to the instructional team that they felt better prepared to perform reaction engineering work due to their participation in the project.

Theme 3: Project Improvements through Intentional Scaffolding

Associated codes:

- Scaffolding, Structure, and Timing
- Support from Tech and AI
- Project Design Recommendations

The instructional team described areas for project improvement, but most recommendations came with tradeoffs that need to be carefully addressed. The team saw intentional scaffolding as essential for a successful community-based project, with project milestones and support systems needing to be carefully aligned with other course components, as highlighted by the following two quotes:

> "I think that for these projects, it's essential to have well-defined project prompts, but still keep them largely open-ended to allow for creative solutions."

> "Another challenge was them seeing that the project was done in tandem with homeworks, a quiz, and exams, so they could feel overwhelmed. This was particularly exacerbated at the start when they were having to think about content and problem definition for things they hadn't yet learned."

In addition to adjusting prompt specificity and milestone timelines, the instructional team identified other areas of possible project improvement. One idea included a phased approach to technology use that emphasizes applying conceptual reasoning prior to receiving AI support. Other recommendations included periodic in-class peer review sessions, adding an experimental project portion, and implementing more alternative assessment techniques for project grading.

Final Presentation and Community Partner Results

The final presentation was a huge success, with almost 200 attendees. Attendees included faculty, staff, and students from across Carnegie Mellon University's different colleges; visitors from the community partner; and industry representatives from the sponsor PPG. Pictures of the event are shown in Figure 6.

Figure 6. Photos of the Reacting with Nature final poster presentation.

The partner organization expressed delight to the instructional team, highlighting how fun and smooth the process of working together was. They were eager to repeat the project in the future, and offered to accommodate project prompt changes into the student tours. Staff at the partner organization expressed interest in the reactor models that the students presented but have not reported using them for design or troubleshooting purposes.

Discussion

I. Summary of the Project's Impact on Students

Overall, the project was found to be initially challenging for many students, but ultimately the class overcame these challenges and showed active engagement and satisfaction with the project. The mid-semester and instructional feedback highlighted students feeling overwhelmed and uncertain at the project start due to difficulties with the project's open-ended nature, milestone scheduling, and navigating literature. Even with these struggles, students reported appreciation of the practical relevance of the project and support from the project CA, while offering clear suggestions for future improvement.

Details of FCEs and instructional reflections highlighted how students ultimately enjoyed the project, feeling that it helped them better understand theoretical concepts by connecting them to engineering practice. This enjoyment was expressed through creative videos and poster techniques, verbal expressions of satisfaction, and positive LinkedIn posts and end-of-semester feedback. Despite struggling with the difficult nature of the course, many students discussed the project and presentation as highlights of their semester. The project was cited as improving student's teamwork and resilience to uncertainty in problem solving, offering them experiences and skills that prepared them for engineering interviews and professional work.

II. Limitations

This paper includes retrospective descriptions of the project development process and student and instructional reflection data for project evaluation. While these insights provide relevant design and implementation considerations for community-based course projects, it does not offer generalizable results. Designing a research study with controlled data collection from the outset of project development may have yielded clearer quantitative and qualitative findings that better detail the impact of the project on students, instructional staff, and the community partner. Additionally, memoing throughout the development process may have improved the ease of paper writing and the accuracy of reported development challenges and decisions.

III. Project Continuation and Recommendations

The project was well received by the students, instructional team, chemical engineering department, and community partner, leaving all eager to iterate it for future semesters. To iterate the project, the following changes have been considered from student and instructor feedback:

- Provide sufficient project guideline and prompt detail to ensure clear expectations while still maintaining constructive struggle in navigating uncertainty
- Align project milestone deadlines to ensure necessary content has been covered in class and to minimize overlap with other course assignments and assessments
- Consider in-class peer review sessions or working time
- Consider experimental project portion
- Consider intermittent milestone checkpoints for additional scaffolding
- Consider requiring unaided conceptual reasoning prior to allowing AI/internet support

A new Project CA was hired for the 2025-2026 academic year to assist with revising the course project according to the above recommendations. Additionally, the new Project CA developed prompts incorporating global water filtration challenges including the following:

1. Mining Contaminant Removal
2. Desalination for Drinking Water
3. Indirect Potable Reuse in Orange County, CA
4. Direct Potable Reuse in Namibia (Toilet-to-Tap)
5. Chlorine Residual Standards in the U.S.

For others interested in developing community-based course projects, here are some recommendations that emerged from student and instructor feedback:

- Community projects are good press, market them to departmental and college leadership for assistance
- Search for partner organizations with educational missions and event spaces
- Former student undergraduate CAs can be cost effective and bring relevant course experience
- Leverage existing university/department industry partnerships for event funding
- Adding a project requires cutting other content
- Be ready to iterate and solicit feedback; plan any feedback mechanisms and/or research early on
- Incorporate alternative grading and resubmissions if possible to reduce student stress and encourage productive failure
- Incorporate structured peer feedback and group member evaluation through Canvas FeedbackFruits or other similar programs to develop students' collaboration skills
- Ask your community partner what they help to gain from the project for reciprocity

Conclusions

This paper documents the design, implementation, and evaluation of a semester-long, community-based project embedded within a third-year chemical reaction engineering course. This project was developed in partnership with a local sustainability nonprofit that operates nature-based water reuse systems. The project engaged students in modeling real water treatment processes using reactor theory, literature-derived parameters, and operational data. The project was scaffolded through four milestones emphasizing literature review, model development, peer feedback, and professional communication, culminating in a public poster presentation hosted by the community partner. A Project CA was hired from among former students to lead project development; their role included partner coordination, student advising, and project assessment, enabling sustained project support while minimizing additional instructor workload.

Student feedback and instructional reflections indicate that the project was initially challenging but ultimately rewarding for the students. Midsemester feedback highlighted students' feelings of uncertainty and overwhelm, and a perception of misalignment between project milestones and course instruction, particularly early in the semester. However, end-of-semester responses and instructional reflections revealed that students grew more comfortable navigating ambiguity, developed stronger engineering judgment, and increasingly engaged with the project due to its real-world relevance. Students frequently described the project as enjoyable, meaningful, and professionally valuable, citing its role in strengthening conceptual understanding, teamwork skills, and career readiness. Instructional staff observed increased student ownership, creativity, and confidence over time, alongside evidence that students leveraged the project in resumes, interviews, and professional social media platforms.

For instructors considering similar projects, several recommendations emerged. Community-based projects will likely be more successful if expectations are clearly articulated, milestones are aligned with content coverage, and sufficient instructional support is recruited. Undergraduate former students can serve as highly effective Project CAs, offering disciplinary familiarity, credibility with students, and logistical support at relatively low cost. Instructors should be prepared to iterate project design, reduce or restructure other course content, and incorporate mechanisms such as peer review, resubmissions, and guided use of AI to balance rigor with productive learning experiences. When carefully designed and supported, community-engaged projects can enhance student learning while helping engineering programs better prepare students for the uncertainty and complexity of real-world practice.

This Institutional Review Board Considerations

The Cornell University Institutional Review Board for Human Participant Research found that this project does not meet the regulatory definition of human subjects research, and, therefore, no IRB approval or exemption is required.

Appendices

Appendix I. Midsemester Feedback Form Questionnaire

Note: All questions on the form were open-ended responses unless indicated with response options through sub-bullets.

- What topics did you find challenging on Exam 1 material and why?
- Did you use generative AI tools to help you learn concepts for this class?
  - Yes
  - No
- What specifically did you use AI tools to do?
- Did working on the optional homework problems to prepare for the exam?
- How many hours are you spending a week on homework?
  - <5 hrs
  - 5-8 hrs
  - 9-12 hrs
  - >12 hrs
- Are in-class partner problem work-throughs and activities helping you learn the concepts?
  - Yes
  - No
- On a scale from 1 to 5, how well do you think the Reacting with Nature course project is going so far?
  - 1 – Not well at all
  - 2
  - 3
  - 4
  - 5 – Extremely well
- What feedback do you have on the course project, the project instructor Gabe, and ways to improve the project for the second half of the semester and/or in future semesters?
- Any constructive comments for the TAs?
- What specific activities can we do in-class to help you learn the material better?

Appendix II. Faculty Course Evaluation Questionnaire

Note: All questions on the FCE questionnaire were on a Likert-scale with values between 1 – 5.

- Overall how would you rate this faculty's teaching?
- Does the faculty member show respect for all students?
- Does the faculty member explain the subject matter of the course (e.g. concepts, skills, techniques, etc.)?

- Does the faculty member demonstrate the importance and significance of the subject matter?
- Does the faculty member provide feedback that helped students improve their performance?
- Does the faculty member provide a clear explanation of the learning objectives or goals of the course?
- Does the faculty member provide a clear explanation of the course requirements?
- Does the faculty member display an interest in students' learning?
- How would you rate the overall quality of the course?
- On average, how many hours per week have you spent on this class, including attending classes, doing readings, reviewing notes, writing papers and any other course related work?

Appendix III. Instructional Reflection Prompt

Please write a 2–3 paragraph reflection describing your observations of student engagement, learning, and challenges during the Phipps Center for Sustainable Landscapes water-reuse project. In your response, reflect critically on the project's impact on student learning, teamwork, and motivation; identify areas where the project or course structure could be improved; and offer recommendations for instructors at other institutions who may adopt a similar community-based project model.

Appendix IV. Codebook for Midsemester Feedback Form

Theme	Definition	Code	Definition
Navigating Ambiguity in an Open-Ended Project	Students experienced uncertainty and interpretation challenges as they engaged with the intentionally open-ended project prompts, expectations, and modeling decisions.	Unclear Expectations and Prompts	Student perceptions that project goals, prompts, rubrics, or milestone expectations were ambiguous, vague, or difficult to interpret, particularly early in the project.
		Difficulty Accessing or Using Resources	Challenges related to finding, organizing, or effectively using provided resources (e.g., Canvas files, supplemental materials).
		Uncertainty and Direction-Seeking	Students' discomfort with open-endedness and lack of confidence in whether they were "on the right track," particularly regarding modeling choices and assumptions.

Structural Misalignment and Cognitive Load	Students perceived that project timing, milestone sequencing, and workload intensity—particularly relative to course content coverage and other assessments—contributed to feelings of overload and stress.	Data and Parameter Scarcity	Challenges stemming from missing, uncertain, or unrealistic data needed for modeling, including rate constants, concentrations, or system-specific parameters. Challenges from lack of literature
		Cognitive Load and Time Pressure	Feelings of being overwhelmed due to project workload relative to other course demands, exams, and concurrent projects.
		Timing and Sequencing Misalignment	Concerns that project milestones, tours, or modeling tasks were poorly aligned with course pacing or content coverage.
Instructional Support and Perceived Value	Students evaluated instructional guidance, feedback, and support structures and identified room for growth. They recognized the project's practical relevance and educational value.	Support from Project CA	Perceptions of the project course assistant's availability, feedback quality, and role in helping students navigate ambiguity.
		Perceived Value	Recognition of the project as engaging, meaningful, or valuable. Absence of negative feelings or discontent.
		Suggestions for Improvements	Concrete recommendations for modifying project design in future iterations such as group size changes, in-class work time, or more milestones or examples.

Appendix V. Codebook for Faculty Course Evaluations Open-Ended Responses

Theme	Definition	Code	Definition

Perceived Value of Project	Students found the project fun, engaging, and practically relevant, citing it as a highlight of the class despite the need to improve timing of milestones in the future.	Project Enjoyment	Expressions of interest, enjoyment, or positive affect toward the project experience, including statements describing it as fun, enjoyable, or valuable.
		Project Real-World Relevance	Recognition of the project as meaningful due to its grounding in a real-world or local system, in contrast to hypothetical problems.
		Project-Supported Conceptual Understanding	Statements indicating that the project helped students understand reactors, course concepts, or applications more deeply than lectures or homework alone.
		Project Structure and Pacing Suggestions	Constructive feedback related to project milestones, workload distribution, clarity, or scaffolding (e.g., adding checkpoints, spreading deadlines).
Engagement and Challenges with Overall Course	Students found the course overall valuable but challenging due to its difficult content and exams, many components, and large workload.	Course Workload and Time Intensity	Perceptions that the course required a high or disproportionate time investment relative to credit hours, often referencing homework, coding, or exams.
		Course and Instructor Approval	Positive evaluations of the course and/or instructor that reflect overall satisfaction, perceived instructional quality, instructor care, responsiveness to feedback, or enjoyment of the course as a whole, without specific reference to the project.
		Course Difficulty and Assessment Stress	Statements describing the course as difficult, stressful, or anxiety-inducing, particularly in relation to exams, grading norms, or expectations of failure.

Appendix VI. Codebook for Instructional Reflections

Theme	Definition	Code	Definition
Developing Engineering Skills through Application	The community-based project helped students develop core engineering skills by engaging them in open-ended, real-world problem solving that required them to navigate uncertainty, exercise engineering judgment, and take ownership of design decisions.	Engineering Judgment and Evaluation	Student development of engineering intuition, critical reading of literature, and the ability to evaluate assumptions, parameters, and model limitations when applying theory to novel contexts.
		Navigating Ambiguity and Uncertainty	Students' discomfort with open-ended problem definition and/or gradual development of confidence in working without a single correct answer.
		Student Engagement and Ownership	Observable student investment, motivation, creativity, and sense of ownership over project direction and outcomes.
Preparing Students for Engineering Careers	The project supported students' professional preparation by connecting theory to practice, cultivating teamwork and collaboration skills, and providing experiences that students could leverage for resumes, interviews, and future engineering work.	Career Preparation	The extent to which the project supported resume building, interview readiness, and professional identity formation.
		Teamwork and Collaboration Skills	Student learning related to collaboration, role negotiation, time management, communication, and managing interpersonal challenges.
		Theory into Practice	The use of a community-based project to connect reaction engineering concepts to real industrial, environmental, or research contexts.
Project Improvements through Intentional Scaffolding	Instructional staff discussed how intentional scaffolding—including structured prompts, milestone timing, and guided use of technology and AI—can better	Scaffolding, Structure, and Timing	The role of prompts, checkpoints, milestone sequencing, and alignment with course content in supporting or hindering student learning.
		Support from Tech and AI	Student engagement with computational tools and AI, including tensions between

	support student learning while preserving productive challenges and improving the overall effectiveness of project implementation.		conceptual reasoning and overreliance on automated solutions.
		Project Design Recommendations	Instructional staff suggestions for improving project design, including peer review, assessment structure, resubmissions, teaming approaches, and partner coordination.

Appendix VII. Sample Rubric from Milestone 2

Criteria	Excellent (20 Points)	Good (15 Points)	Needs Improvement (10 Points)	Needs Significant Improvement (5 Points)	Points
Reactor Model Description	The reactor model is thoroughly explained, incorporating chemical reaction engineering principles. Assumptions are clearly justified, and the choice of reactor type is well-aligned with the process. The model's behavior and its application to the water treatment process at CSL are clearly demonstrated. This section fulfills and exceeds all requirements in the section guidelines above.	The reactor model is mostly logical with adequate explanations, but may need further detail or explanation. The assumptions are generally explained, but could be better justified. The application to CSL is clear but may need more detail or further connection to reactor behavior.	The reactor model is described in a basic manner, with unclear or incomplete assumptions. The choice of reactor may not be fully justified, and the application to CSL processes is vague or underdeveloped. The link between the model's behavior and its practical application is weak. Several of the section guidelines above are not fulfilled.	The reactor model is missing, incorrectly described, or lacks sufficient justification. The assumptions are poorly explained, and the application to CSL processes is misaligned or missing.	/20
Explanation of Alignment with CSL Water Processes	The explanation of CSL's water treatment processes is thorough and well-connected to the reactor model. The model is effectively integrated into the relevant stage of CSL's system, and the justification for its use is strong and clear. Comparisons to other possible models are made, supporting the choice of the reactor. This section fulfills and exceeds all requirements in the guidelines above.	The understanding of CSL processes is clear, but the integration of the reactor model may need further explanation or justification. The connection to the specific stage of the CSL system is generally present but may require additional detail or support. Comparisons to other models are not extensive but present.	The understanding of CSL processes is somewhat unclear or incomplete. The reactor model's integration into the system is weak or underdeveloped. Justification for the model choice may lack depth, and comparisons to other models are minimal or not fully explained. Several of the section guidelines above are not fulfilled.	The understanding of the CSL processes is missing or incorrect. The reactor model does not integrate well with the system, and justification for the choice is weak or absent. Comparisons to other models are missing or irrelevant.	/20

Clarity and Quality of Calculations **(***Note:* Mistakes are likely at this stage of the project and part of the learning process; your grade will depend on your level of effort and if you properly implemented changes and improvements based on the feedback from Milestone 1 and your meeting with the course assistant.**)**	Calculations are detailed, thorough, and illustrate a top-tier effort. The calculated values address the technical scope of the project. All feedback from Milestone 1 and the meeting with the CA has been explicitly addressed and implemented. This section fulfills and exceeds all requirements in the guidelines above.	Calculations are generally accurate but may need more detail or refinement. -or- The calculations do not completely align with the requested prompt/scope of the project. -or- One of the major requests/points of feedback from milestone 1 have not been properly addressed/explained.	Calculations are unclear, lacking in detail or accuracy. -or- The calculations do not align very well with the requested prompt/scope of the project. -or- Two or three of the requests/points of feedback from milestone 1 have not been properly addressed/explained. -or- Several of the section guidelines above are not fulfilled.	Calculations are missing or poorly done. -or- The calculations do not align at all with the requested prompt/scope of the project. -or- Most or all of the requests/points of feedback from milestone 1 have not been addressed/explained.	/20
Quality of Equations and Figures	Equations are clearly presented, correctly formatted, and fully support the reactor model. All necessary variables are defined. Assumptions and derivations are clearly explained where applicable. -and- Figures are well-organized, labeled clearly with appropriate captions. Visuals enhance the understanding of the reactor model and calculations, supporting the text with clarity and precision.	Equations are mostly correct and clear, but some may need refinement or more detailed explanations between them. -or- Figures are present and labeled but may need further detail for clarity or to better support the explanation. Some figures may not be fully relevant or have small but notable formatting issues.	Equations are incomplete or unclear. Some assumptions or derivations may be missing or not well explained. -or- Figures are unclear or poorly labeled. They may not support the analysis effectively or may be hard to interpret.	Equations are missing or very poorly formatted. Assumptions and derivations are unclear or missing. -or- Figures are missing, poorly labeled, or irrelevant. They fail to support the reactor model or calculations.	/20

Draft Model Feasibility	The model is realistic, feasible, and aligns excellently with the project goals. -or- If there are aspects that are not feasible or realistic, there is a comprehensive plan to address them prior to Milestone 3. -and- This section fulfills and exceeds all requirements in the guidelines above.	The model is mostly realistic but there are noticeable adjustments for feasibility or goal alignment that haven't been thoroughly addressed. If there are aspects that are not feasible or realistic, there is a plan to address them prior to Milestone 3, but it requires more detail.	The model has feasibility issues or needs significant adjustment. Any unrealistic and infeasible elements have a very weak plan to address them prior to Milestone 3. -or- Several of the section guidelines above are not fulfilled.	The model is unrealistic or not feasible within the project scope. There is no plan to address infeasible and unrealistic elements.	/20
Total					/100

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