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Active Learning in an Upper Division Computer Networks Course

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Abstract

Computer Networks is an important course in most undergraduate curricula in computing disciplines. In most curricula, it is the only course on the topic. Students must get a conceptual understanding and retain the materials from this course. It has been demonstrated that active learning can positively impact academic performance and success. This paper presents the author's experience in designing and implementing active learning in an upper-division computer networks course.

Introduction

Computer Networks is an undergraduate course that is included in most curricula in the computing disciplines. It is listed as an element of computing knowledge[1 2] in the ACM recommended curricula. It is usually the only course on the topic listed as a core course in most programs. The textbooks[3,4,5] are an indication of how broad and deep the topic is.

In the last three academic years, the courses in the author's department have had a failure rate of 2%, which amounts to 16 students. These are students who would potentially be delayed in their 4-year graduation timelines. Students who are underrepresented minorities have had a GPA gap of 0.28, higher than the historic average of 0.26. Active learning has been shown to be an effective strategy to improve students' participation and engage them to take an active role in their learning[6]. It is also shown to reduce equity gaps[7]. However, it is still not adopted in most classrooms, which continue to be taught in traditional lecture-style sessions[8].

This paper presents the author's experience in designing and implementing active learning for an upper-division computer networks course. The author taught this course for three semesters - Fall 2021, Spring 2022, and Spring 2023. This course is the first introduction to computer networks for students in computer and software engineering majors. The paper will cover the considerations for designing activities, the student handout designs, experience with implementing the activities, and show results on how the active learning implementation improved performance.

Active Learning Motivation

Active Learning is a pedagogical approach that leads students to think and engage with materials by doing rather than listening[9 10 11]. A meta analysis of studies that compare traditional teaching to active learning approaches shows that active learning improves exam scores and reduces failure rates[12]. Despite the well-known benefits of active learning, its adoption faces resistance[8]. This work is motivated by the success of active learning reported in literature and the techniques used by the author are inspired by the works of Felder and Brent[13]

Active Learning Considerations

The author used non-graded pop-quiz style Q&As, 5-minute group discussions, and activities spanning most of the class duration. The pop-quiz style questions were included to make sure that the instructor was not speaking for more than 10 minutes without giving the students an opportunity to check their knowledge. Some of the questions were prepared in advance, but most questions were posed based on students' perceived level of confusion when topics were presented to them. Since computer networks use clearly defined protocols and algorithms, discussions should be used as tools to understand the design considerations or to solve practice problems.

The main considerations of the author for designing full-class activities for a traditionally lecture-style course with a broad range of topics are as follows:

- Topics to be taught using activities: For a course such as computer networks, where a majority of the course discussion involves clearly defined protocols, it is a challenge to determine what topics can be taught using activities, and what topics can be still taught using other active learning
- Timing: The activities have to be introduced at the right time, so that students had enough knowledge to reason about the problems.
- Relatable real-world problems: The activities needed to be abstracted and mapped to relatable real-world problems so that do not become extended practice problems, but force students to reason about the concepts behind protocols and definitions.

In the following section, two types of activities are detailed.

Activities

Propagation delay vs Transmission Delay: Students in the past struggled to understand the difference between propagation delay and transmission delays on the networks. The author designed the following activity to help students arrive at the conclusion on their own. The activity is detailed below.

Compute the total delay to send gossip from snail 1 to snail 2 if no animal takes a break based on Figure 1

Events:

1. Snail 1 passes the message to bird 1
2. Bird 1 flies to tell Panda

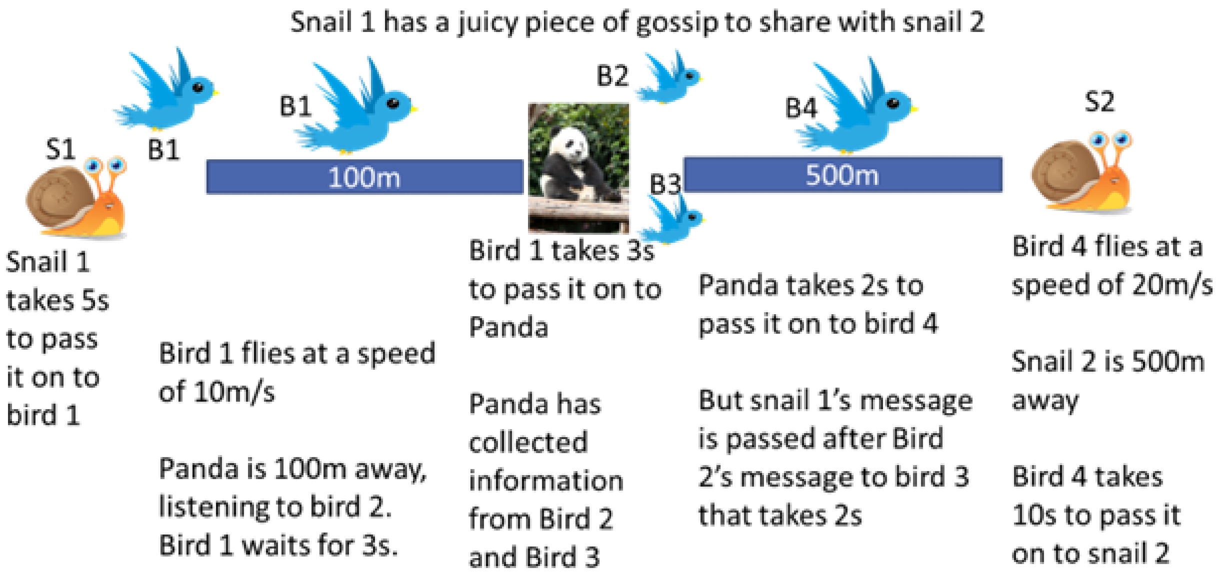

Figure 1: The bird gossip activity

3. Panda is already listening to a message from bird 2
4. After bird 2 is done, bird 1 passes on the message to Panda
5. Panda first shares bird 2's message to bird 3
6. Panda then shares bird 1's message to bird 4
7. Bird 4 flies to snail 2
8. Bird 4 passes on the message to snail 2

Discussion prompts:

1. Break down the delay caused by Panda – how much of it is because of waiting?
2. Can we categorize the different sources of delay?
3. (optional to use if time permits) How does Panda deal with messages from different sources going to different destinations?

The implementation of the activity was done in-class as an activity for a planned duration of 25 minutes, with the following breakdown.

1. 5-minute setup: Students first form groups of 3-4 students. They are first given the time to read the scenario, followed by a check-in to ask for clarifications.
2. 5 minutes for prompt 1
3. 5 minutes to share with the entire class
4. 5 minutes for prompts 2 and 3

5. 5 minutes to share with the entire class

After the activity, we went through the slide deck, similar to a lecture session, to tie the activity to the concept. A practice problem was provided for students to try. This activity was piloted in Spring 2022 and revised in Spring 2023.

To test how well students grasped the concept, the author used a quiz, the midterm exam, an optional retake for the midterm exam (with different questions), and a final exam. The quiz could be taken any number of times with questions picked from a question bank and from formula questions on the learning management system.

Transmission Control Protocol (TCP) sequence numbers Another major point of struggle for students was sequence numbers in TCP. Most textbooks introduce TCP step-by-step by changing the assumed capabilities of the underlying network layer. However, despite instructor-led discussions encouraging students to reason about the protocol, sequence numbers were harder for students to grasp. The following activity provides an imaginary scenario to help students reason about the protocol as a puzzle.

Scenario: Two astronauts want to communicate with each other. The sender is in Pod A and the receiver is in Pod B. The sender sends the mathematical operations shown in Figure 2, using four messages, for the receiver to compute. They use the teacup service to send the messages. The teacup service guarantees that the messages will arrive at the receiver and will arrive in the order in which the messages were sent.

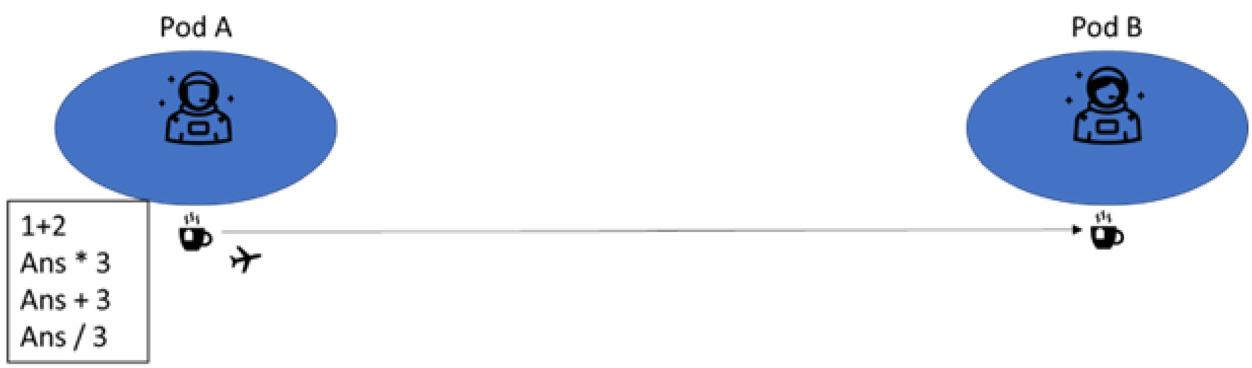

Figure 2: The TCP activity

The teacup service uses a paper-plane service that can find the receiver pod and send messages to it via paper planes. Each paper plane can only fit one message. Refer to Figure 2 for more details.

Prompt 1: If the paper-plane service guarantees that the messages will arrive at the receiver and will arrive in the order in which the messages were sent, what does the teacup service need to do?

Prompt 2: If the paper-plane service guarantees that the messages will arrive at the receiver and will arrive in the order in which the messages were sent, but there can be errors. E.g., if the sender sends “Ans + 3”, the receiver may receive “Ans – 3” instead. Now, what does the teacup service need to do to provide the service it guarantees?

Prompt 3: If the paper-plane service may lose messages AND there can be errors in the messages received, what does the teacup service need to do to provide the service it guarantees?

Prompt 4: If the paper-plane service may lose messages AND there can be errors in the messages received AND messages may arrive out of order, what does the teacup service need to do to provide the service it guarantees?

The implementation of the activity was done in-class as an activity for a planned duration of 40 minutes, with the following breakdown.

1. 5-minute setup: Students first form groups of 3-4 students. They are first given the time to read the scenario, followed by a check-in to ask for clarifications.
2. 3 minutes for prompt 1
3. 2 minutes to share with the entire class
4. 5 minutes for prompt 2
5. 5 minutes to share with the entire class
6. 5 minutes for prompt 3
7. 5 minutes to share with the entire class
8. 5 minutes for prompt 4
9. 5 minutes to share with the entire class

After the activity, we went through the slide deck, similar to a lecture session, to tie the activity to the concept. When sequence numbers are discussed, we discussed how the numbers could be used in the teacup service. This activity was piloted in Spring 2022 and revised in Spring 2023.

To test how well students grasped the concept, the author used a quiz, the midterm exam, an optional retake for the midterm exam (with different questions), and a final exam. The quiz could be taken any number of times with questions picked from a question bank and from formula questions on the learning management system.

Results

Student feedback Students enjoyed the activities. Everyone present in the class participated. When the topics were then shown on slides, they were able to digest the materials much better.

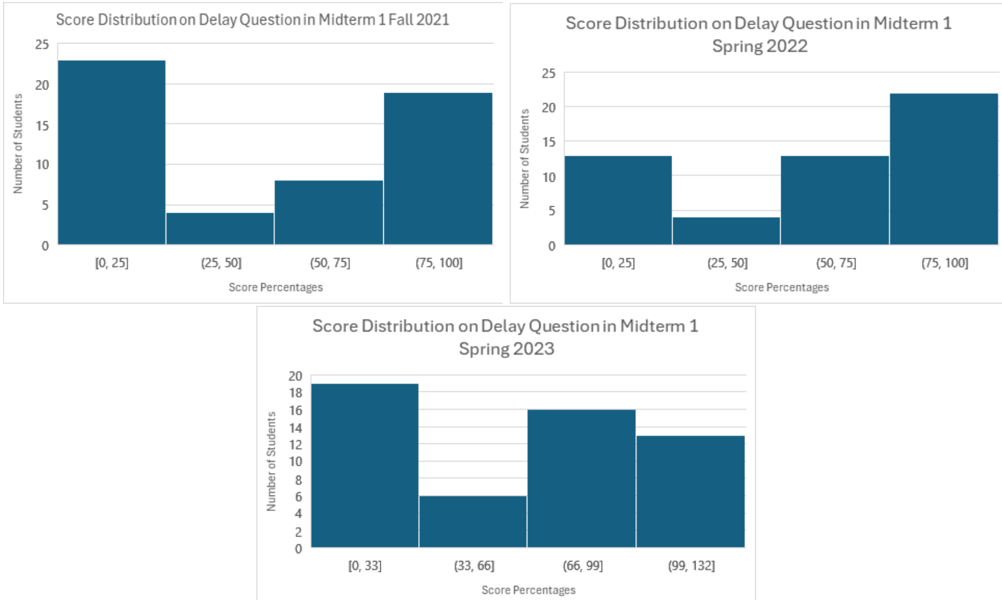

Figure 3: Graphs that capture student grades on questions on network delay testing their understanding of the difference between propagation and transmission delays in the first midterm exam

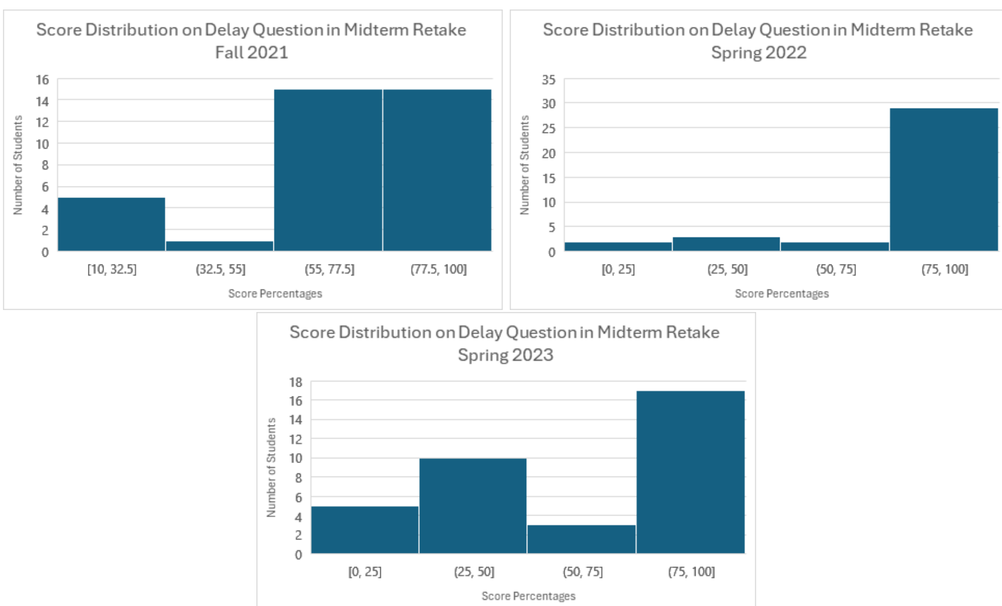

Figure 4: Graphs that capture student grades on questions on network delay testing their understanding of the difference between propagation and transmission delays in the midterm exam retake

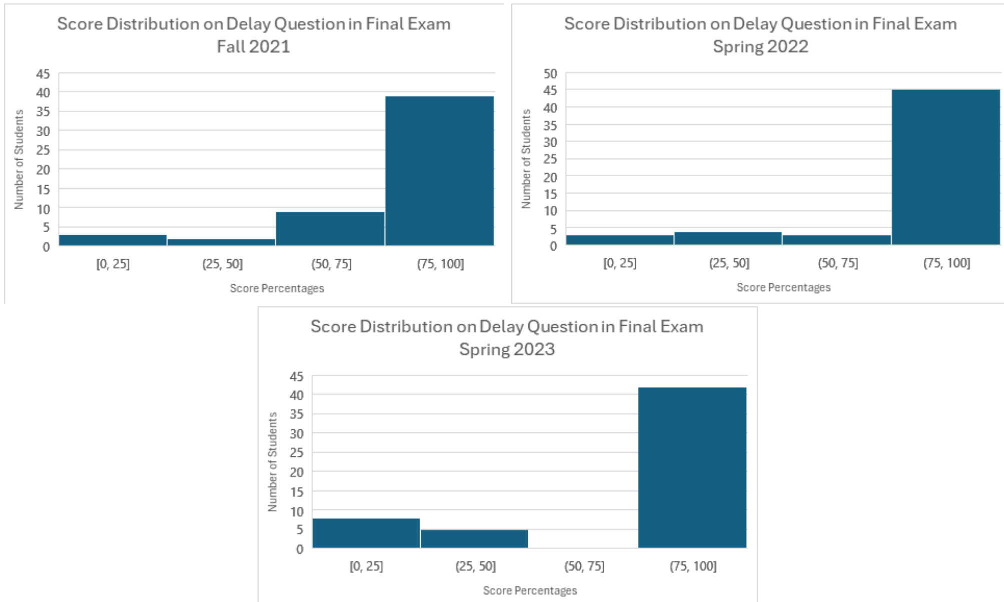

Figure 5: Graphs that capture student grades on questions on network delay testing their understanding of the difference between propagation and transmission delays in the final exam

Performance The students performed better on the pop-quizzes, graded quizzes, and exams as compared to students who were only introduced to the concepts via lectures. As mentioned, the full-class activities were piloted in Spring 2022 and improved in Spring 2023. The score distributions for network delay questions in the midterm exams and final exams are as shown in Figures 3, 4, and 5. The score distributions for network delay questions in the midterm exams and final exams are as shown in Figures 6, 7, and 8. It shows that student performance improved by the midterm retake after the introduction of the activities. It is important to note here that only students who wished to improve their scores took the retake exams.

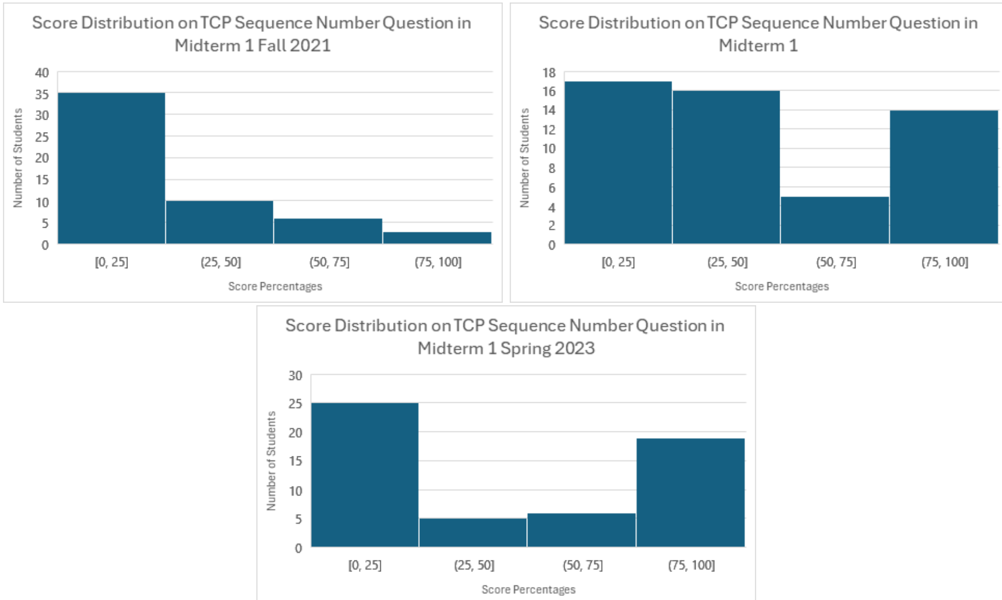

Figure 6: Graphs that capture student grades on questions on TCP sequence numbers in the first midterm exam

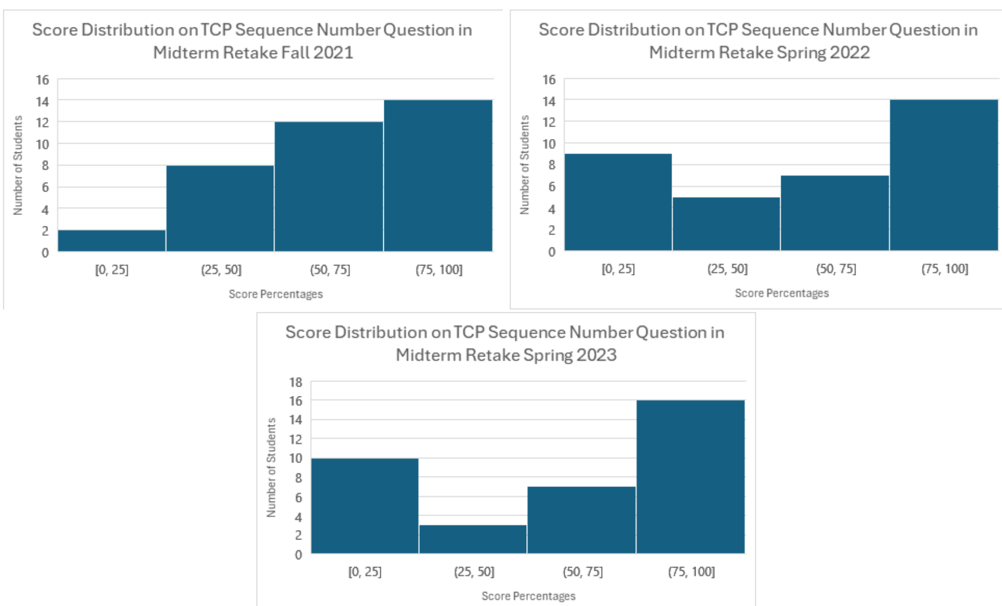

Figure 7: Graphs that capture student grades on questions on TCP sequence numbers in the midterm exam retake

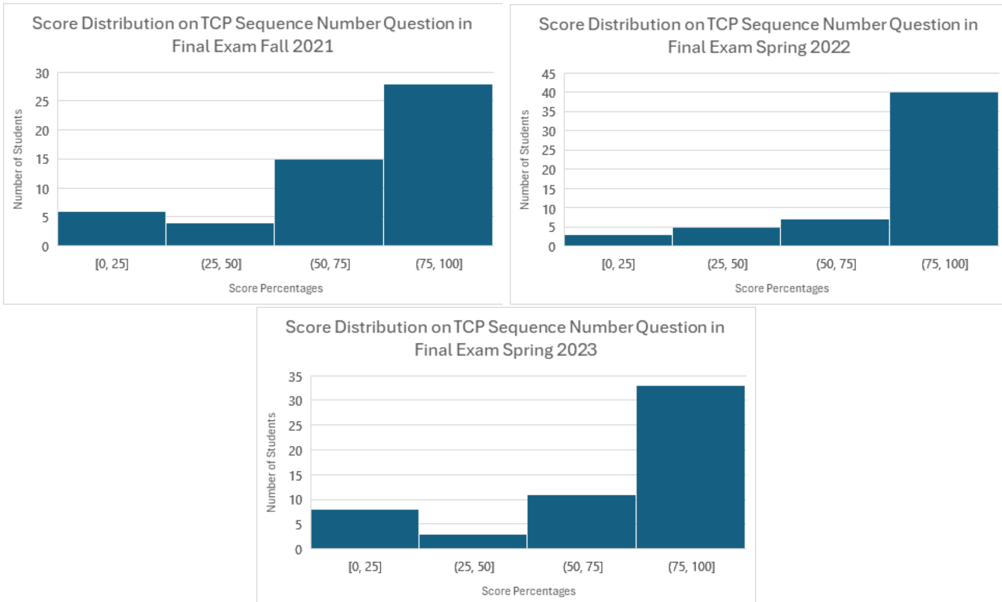

Figure 8: Graphs that capture student grades on questions on TCP sequence numbers in the final exam

Equity gaps: The author is happy to report that there were no reported equity gaps (DFW rates) in the Spring 2022 and Spring 2023 semesters for underrepresented minorities, economically disadvantaged, gender, and first-generation categories.

Conclusions

Overall, the effort to design and orchestrate the activities is not a trivial time investment. Pop-quiz style questions are the easiest to design. As the author prepared lectures slides, planned questions were added into the lecture narrative and additional optional questions were noted to be used in class. Typically, as the lecture proceeded and student answers indicated gaps in knowledge, the instructor would pick from the prepared bank of questions. For 5-minute group discussions, prompts have to be very clear. The instructor prepared topics based on the responses from pop-quizzes and on topics that previously saw poor performance. Preparing these prompts required more thought and preparation than the pop-quizzes.

Finally, the longer activities took the most time investment. The instructor has to strike a balance between relatable and real-world connection and the technical skills the students are intended to acquire. In the pilot for the delay activity in Spring 2022, the author used a lecture slide to describe the activity and used estimates to orchestrate the timings. Students were not informed of the time constraints in advance. As a result, groups progressed in widely varying paces. After that, the instructor used a handout with more clear prompts and timings of each component, along with more support in class by walking around to groups to see how they are progressing. The author's challenge was to let students struggle with the problem and intervene only if groups have trouble starting a discussion or have some members not participating in discussions.

Overall, the author finds that the activities are challenging to design, requiring thought and time, but it is worth the time investment. There are still several limitations to this work, which inform future work. First, there is a need to collect student feedback on how these activities improve their understanding with the use of carefully designed surveys. This is key to also understand how active learning impacts metrics other than performance, such as communication skills and a sense of belonging. Also, this paper only looks at the impact of longer activities. Short activities also need to be formally documented and studied to understand their impact. Finally, the activities presented in this paper are only a first step to develop a well-designed activity for these topics. As future work, the author intends to create a repository of these activities with corresponding assessments to complement the activities.

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