# Specification and Scaffolding in Project-Based Learning of Systems Architecture

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## ABSTRACT

Project-based learning (PBL) through open-ended group projects is praised for fostering technical communication, collaboration, and leadership skills. We examine PBL in the group project element of Web Systems Architecture, an upper-level undergraduate systems course. We investigate learning outcomes, team dynamics, technical communication, and confidence-building. Our observations suggest that while learning outcomes are similarly achieved with and without additional specification and scaffolding, when given a choice for receiving further specification and scaffolding, students are inclined towards more specification and avoid taking risks in open-ended projects. Specifically, 86% of our students decided to choose the scaffolded project stream, and by the end of the project, 41% of the students (58% of survey respondents) indicated their preference for even a more specified project. We explore the factors influencing this choice and discuss design alternatives to further motivate risk-taking, and our initial results using them.

## KEYWORDS

Project-Based Learning; PBL; Scaffolding; Faded Scaffolding; Specification; Web Systems; Systems Architecture; Cloud-Based Systems

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## 1 INTRODUCTION

Project-based learning (PBL) [1][10] is an effective instructional technique in computer science [5] and engineering [15], praised for fostering technical communication, collaboration, and leadership skills. Computer science community has reported benefiting from PBL in programming and software engineering [6][17][20]. However, PBL remains less explored in the context of systems courses [22] [9] in computing science. We present our approach to PBL in the third offering of an upper-level undergraduate systems course through a multi-step group project, worth 30% of the final grade.

As a form of socially constructed learning, PBL draws upon the "learning by doing" philosophy of John Dewey [11] and social support concepts of Lev Vygotsky [21]. According to Mills et al. [15] and Blumenfeld et al. [1], students who participate in PBL are motivated by the opportunity to work on real-world projects and also develop better understandings of the application of their knowledge in practice. Open-ended projects are believed to further facilitate this process by providing the opportunity for further progress in a direction of student interest [3]. On the other hand, as noted by Hmelo-Silver et al. [8], student-centered learning, like PBL, requires scaffolding and guidance to facilitate student learning. Scaffolding is proven to be effective in increasing participation [12] and enabling project-based learning for more diverse student cohorts [20]. In this work, we investigate the effect of specification and scaffolding on learning while measuring risk-taking in open-ended projects. Student perceptions of project specification and complexity inspired our question, and the presented approach.

We focused on specification to assist students in achieving the intended learning outcomes of PBL in a systems course. We integrated regular bite-sized cloud-platform deployment instructions called Interactive Sessions (ISs) for bridging the gap often encountered in applying the theory in practice. In addition, we provided further scaffolding through an elective project stream. Inspired by works of McNeill et al. [13], and Coenrad et al. [2], we implemented Stream (1) to provide scaffolding by integrating templates and starter files, and references to course materials. Stream (2) offered an open-ended choice while meeting the project step technical requirements.

We investigated the impact of specification and scaffolding, exploring "***How providing specification and scaffolding can affect achieving advanced outcomes in group projects?***". We conducted multiple surveys and analyzed project submissions and all course grade components. We analyzed team dynamics, communication, confidence building, and performance, and paid attention to variations in experience among students. Our findings suggest great teamwork experience and confidence-building within student-formed groups as well as student-reported improvements in technical communication skills. Our performance measures also suggest achieving learning outcomes, and impact of group project in enhancing student learning outcomes.

Contrary to our initial expectations, the additional scaffolding provided in form of project stream choice did not improve the student perception of project complexity. However, it significantly reduced the number of students attempting open-ended project stream or risk-taking within the scaffolded project to include self-interest in any form divergent from the provided baseline. We analyze these observations and offer insights to alternative approaches.

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**Table 1: Course Offerings: (a) Course Elements and Grade Breakdown (b) Project Steps & Timeline**

| **Element** | F20 | **Sp21** | F21 |
|---|---|---|---|
| Four Quizzes | 15% | **15%** | 15% |
| Midterm | 10% | **10%** | 35% |
| Final Exam | 30% | **30%** | 0% |
| Eight ISs | 5% | **5%** | 5% |
| Four Assignments | 10% | **10%** | 15% |
| Group Project | 30% | **30%** | 30% |

| **Project Step** | **Grade %** | **Timeline (Days)** | | |
|---|---|---|---|---|
| | **Sp21** | F20 | **Sp21** | F21 |
| Step One: Team & Stream | **5%** | 5 | **14** | 7 |
| Step Two: Title & Static Files | **15%*** | 7 | **11** | 21 |
| Step Three: Project Iteration I (PI-I) | **30%** | 14 | **14** | 14 |
| Step Four: Project Iteration II (PI-II) | **30%** | 14 | **17** | 14 |
| Step Five: Presentations & Outcomes | **20%*** | 7 | **7** | 4 |

## 2 COURSE COMPONENTS & PROJECT

This study details our approach to PBL in the third offering of an undergraduate course on web systems architecture offered during **Spring 2021 (Sp21)**. Web Systems Architecture is an upper-level undergraduate systems course covering topics such as the cloud, virtualization, containerized workloads, container orchestration, distributed databases, serverless computing, micro-services, messaging, and models for building and maintaining scalable web systems for different application use cases. It is offered as a three-credit course within a 13-week semester. The previous offerings include in-person with transition to online during Spring 2020 (Sp20), followed by fully online offering throughout the pandemic during Fall 2020 (F20), and Spring 2021 (Sp21). The components of the course and their grade weight are depicted in Table 1(a) for F20, and Sp21, and F21 offerings. The only difference between F20 and Sp21 offerings was additional specification and scaffolding provided for the group-project in Sp21 offering of the course. We detail the approach for providing additional scaffolding in section 2.2.

The course includes theoretical background as well as hands-on experiences in a public cloud platform. The theoretical components of this course are covered in lectures and tested in four biweekly homework assignments, four biweekly quizzes, and one mid-term and one final exam. For Sp21 offering, the remote lectures were recorded during a synchronized zoom lecture, and made available on YouTube after the class. To connect the theory with practice, we integrate regular bite-sized cloud-platform deployment instructions called Interactive Sessions (ISs). For Sp21 offering, ISs were offered on AWS Educate [4]. ISs are provided as Canvas quizzes including step-by-step instructions for the cloud platform. A question is presented at the end of each step. It is designed to ask for student observations and learning during the step. ISs benefit from labor-based (a.k.a. mastery-based) grading to motivate learning by doing, and repetition to correct mistakes: Students could perform the interactive sessions as many times as they wish and the correct answers are provided at the end of each attempt. The repetition solidifies learning and enables students to enhance grades through additional attempts, knowing the answers after each attempt.

A multi-step course project, worth 30% of final grade, performed in student-formed groups, is designed for enabling students to use their knowledge in building a real-world web system. The group project starts in the second half of the semester. It includes five steps, including two main technical iterations. The project steps, their timeline, and weight in project grade are discussed in section 2.1 and depicted in Table 1(b) (Items marked with *, steps two and five, had different weights in F20, 5% and 30% respectively).

### 2.1 Project Steps

In the first step of the project, the students are required to form teams of size five and select their project stream. We also provide the students with specification of roles and rotations that they need to perform in each step of their project in their group. The roles are the ***architect***, the ***owner***, and the ***facilitator***, and ***two developers***. The roles are designed based on agile project management methodologies, currently in use in the industry. While the whole team designs, implements, and deploys the project, the architect is responsible for the correctness of the system architecture. The owner is responsible for the features of the web service, and the facilitator is responsible for team coordination and cooperation throughout each project iteration. The students rotate the roles in the second iteration of the project.

During the second step, the teams choose their project title within the "social good" theme, independent from technical requirements. Community Bank, Web Service for Helping Newcomers to a Community, Teaching Unprivileged Kids, Community Equity Fund, and Online Book Club were sample project titles provided as an introduction to the project theme. Multiple variations of community banks, book clubs, exchange hubs, and educational systems with different features were among the titles chosen by the students, turned to successful projects. The students are also required to set up the static part of their web system during this step, requiring storage set up and initial front-end development. Software development is not the purpose of this project, and minor coding is required for cloud functions, automation scripts, and configurations. Therefore, given the title, students can use open-source, or their previous code from other courses for different components and customize them based on technical requirements. The challenge is in the solution architecture and cloud deployment of the adopted code base, given technical specifications such as use of Microservices architecture, serverless, or container-based deployments.

The next two steps (PI-I & PI-II), are called project iterations and are the main technical parts of the project. During these steps, the project teams build their web systems while rotating in their roles. In each iteration, we define a set of technical goals. The students meet the technical goals in the context of their proposed title. The technical submission made at the end of each iteration includes the deployed web system on the cloud platform, together with a report on the system design. Teaching assistants ensure cloud platform resource usage, and correct mapping of the corresponding deployment to the proposed design.

At the final step, after receiving the feedback for each technical iteration and applying the proposed changes, the project teams present their web system and their project outcomes to the class. They also provide the link to their live web system for peer interaction and reviews. The groups also submit project outcomes and argue learning and contributions.

## 2.2 Specification and Scaffolding

To measure the impact of additional specification and scaffolding, the project in the Spring 2021 (Sp21) offering included additional scaffolding through an elective project stream. The stream choice (1) implemented scaffolding by integrating templates, starter files, and references to related course materials. It included providing template files, including static HTML and CSS file python code for lambda functions, YAML configuration files, front-end and back-end code samples, sample general design presentation, frequently asked questions with answers, and details about relating lecture content and interactive sessions to project deliverable as well as additional information about the main structure of the program in steps three and four of the project. Students adopt starter files for content and context while they design and deploy the web architecture to meet the technical goals.

In Stream (2), students were free to implement their own project (from scratch, from previous projects, or using properly referenced and copyright-checked resources) as long as they meet technical goals of each project iteration. The technical requirements were within those explored in the class, however, are not specified in the level of details discussed in course materials and interactive sessions. Since choosing this stream shows additional risk-taking, additional optional tasks to gain bonus points are included as motivation for further technical challenges in this stream. The students made their stream choice in Step One of the project, but were allowed to switch streams any time along the way.

# 3 EVALUATION

Web Systems Architecture Spring 2021 (Sp21) offering included 70 undergraduate computer science students in third or fourth year of a bachelor program. We used student access data, performance data, three surveys, as well as questions accompanying project step submissions to measure learning outcomes, motivations, excitement, and confidence. We asked the students to (1) form their groups, (2) discuss and ensure equal individual contribution at each step. We asked them to report on contribution on each project iteration (steps three and four). We also designed self-assessment, and excitement and confidence questions accompanying the Step One: Team (and project stream selection), as well as three different surveys: Pre-Project Survey, Mid-Project Survey (after the step three - the first technical iteration), and Post-Project Survey. Table 2 shows the survey timelines and the number of participants in each survey: 67, 40, 39 (38 respondents), and 52 students.

Available performance and participation data included: (1) Performance (grade) on each project steps, (2) Activity and resources spent on the cloud platform, (3) Time spent on related course components (Interactive Session, Additional Scaffolding Materials), and (4) Occasional zoom polls about project progress in the class. The activity and resources spent on the cloud platform (Amazon AWS) were reported through AWS Educate. We used items (1) and (3) for this work. However, it is worth to mention the activity and resource spent on cloud platform were used in providing feedback and checking their project resources while grading, therefore, while not directly used in this work, it has an effect on performance data. The grade analysis, time spent on course components (such as extra information for scaffolding) are measured through Canvas.

We also measured students' exposure to course topics before the start of the project. 67 students responded to our questions (4% no response) as a part of step one. 46% of class students reported little or no knowledge of web systems and cloud-based systems prior to taking this course, 39% reported some knowledge and exposure to the topics, 10% reported prior work or co-op experience with web and cloud-based systems, and one percent (1%) reported to be very knowledgeable in the field. Table 3 summarizes students' self-assessment of knowledge, the percentage in each category, and subsequent performance in course components. The results for categories with 1% (very knowledgeable) and 4% (no response) of students are not included in Table 3 to avoid identifiability.

**Table 2: Survey Timeline and Student Participation**

| Phase | Time | Respondents | |
|---|---|---|---|
| | | **Sp21** | F21 |
| Project Team | Part of Step One | **67** | 19 |
| Pre-Project Survey | Before Step Two | **40** | 14 |
| Mid-Project Survey | After Step Three | **38** | 12 |
| Post-Project Survey | After Step Five | **52** | 17 |

# 4 RESULTS & ANALYSIS

Our results suggest hurdles in measuring the impact of specification and scaffolding in a controlled environment. The measurements in the literature are usually in consecutive cohorts of the same course offering. Our course offerings in Fall 2020 (F20) and Spring 2021 (Sp21) had only one major difference: added specification and scaffolding for the project element. However, we believe this may not provide an acceptable environment for measuring success as different factors may affect a cohort from one semester to another. For example, the general change in a cohort background and fatigue from online education during COVID time are examples of possible differences that could impede the measurement across these cohorts. Therefore, We did not have the possibility of measurement across cohorts due to the timing of course offerings and major shift to online offering during the pandemic.

**Table 3: Student self-assessment of prior knowledge, and subsequent performance of each self-assessment category**

%: percentage of students, PP: average Project Performance, EP: average Exam Performance (weighted average of midterm & final), and CP: average Course Performance, for each exposure category

| Knowledge/Exposure | % | PP | EP | CP |
|---|---|---|---|---|
| Little or No Knowledge | 46% | 81.4% | 78.5% | 79.8% |
| Some Knowledge | 39% | 84.7% | 80.0% | 81.6% |
| Prior Work/Co-op Experience | 10% | 83.6% | 78.1% | 78.4% |

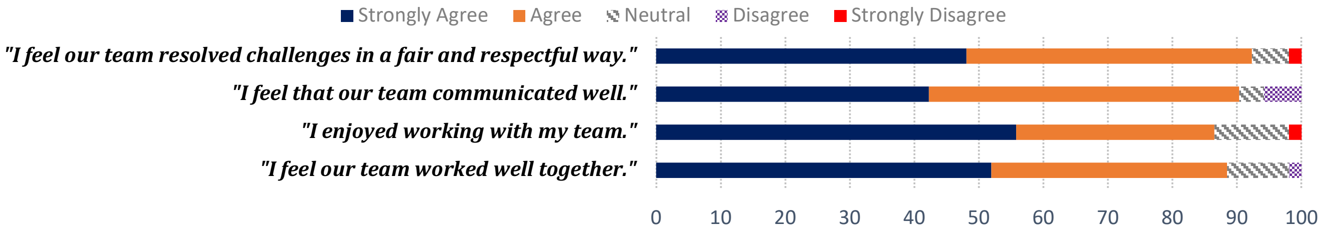

**Figure 1: Teamwork Experience in Student-Formed Groups**

To be able to measure in a controlled way, we took an alternative approach: providing the scaffolded project stream as an accessible option while encouraging the alternative through bonus points to have both options available within a cohort. Students had the opportunity to switch streams during any of the later steps of the project. As their initial choice, only 7% of the students selected the open-ended non-scaffolded project stream. Another group of students chose to switch to stream (2) later during the project, bringing the total percentage of students in the non-scaffolded project stream to 14%.

Based on prior works on scaffolding to increase participation and involvement of diverse group of students [12] [20], we expected to observe reports of less complexity, and the students finding the project easier to do. However, due to Student Experience of Teaching and Courses (SETC) results, the students rated the course easiness 2.74 out of 5 in the Fall 2020 (F20) offering and 2.59 out of 5 in the Spring 2021 (Sp21) offering. This is counter-intuitive to the fact that the only change was providing the option of scaffolding for project steps. Another interesting observation (which is unfortunately not quantifiable in meaningful ways) is that the projects attempted and performed by the F20 Cohort (no additional specification and scaffolded option available) were more complex projects and were performed more thoroughly.

Since the only change between the Fall 2020 (F20), and Spring 2021 (Sp21) was incorporation of additional specification and scaffolding, we believe this might have been the result of fear of missing out incorporated to making a choice of the project streams, especially fear of not receiving additional scaffolding in the choice of project Stream (2) in Spring 2021 (Sp21). This is compared to all students who did not have the option of additional scaffolding in the Fall 2020 (F20) offering. The general difference of background of students in two cohorts, and online fatigue due to continued online offering of courses during COVID-19 pandemic might have contributed to these findings.

To answer our main question, the need for specification and scaffolding, only 7% of the students originally selected non-scaffolded project stream. Another group changed their choice along the project, after the first project iteration. Therefore, by the end of the project steps, only 14% of students had decided to perform their project without additional specification and scaffolding. At the end of this project, 39 students (63% of 52 survey participants) were contend with their project stream choice. 29 students (58% of survey respondents and 41% of class students) still believed that they would have preferred more specification for the project. Only six students (12% of survey respondents and 9% of class students) disagreed with the statement that "I would have preferred to build a more specified project". It is worth to mention that neither of the students who selected the project stream (2) were among the students who reported prior work or co-op experience or abundance of prior knowledge in cloud or web-based systems.

## 4.1 Learning Outcomes

We believe the learning outcomes of the course project were achieved as all project groups successfully delivered their project and reported individual contribution of groups members to the work. In project step one, except for three students who missed the submissions, every group except one received the full grade of the step (5% of the project). The subsequent steps included group submission, and all groups submitted their step deliverable. In project step two (project title), all groups submitted the step deliverable before the step deadline, the average was 12.6 out of 15 (84%) and 64 out of 70 students received a grade higher than the class average.

In project step three (PI-I), all groups submitted the step deliverable before the step deadline, the average of the class was 23.32 out of 30 (78%) and 39 students (56%) received a grade higher than the class average. In project step four (technical iteration two), two groups requested and received time extensions, and all groups submitted step deliverable. The average of the class was 21.31 out of 30 (71%) and 29 students (41%) received a grade higher than the class average. In project step five, all students presented their work in front of the class, and peer-reviewed each others' work. The class average was a near perfect 18.83 out of 20 (94%). We believe the process of peer-review was a contributing factor with a positive impact on students' self-assessment of technical communication.

In addition to the performance in the project phases, two data points about the course performance might be helpful to compare the relation of performance in hands-on and theoretical elements: First, average of the final exam was 35.43 out of 45 (79%) with 37 out of 70 students (53%) scoring above the average. Second average of the midterm exam was 33.47 out of 45 (74%) with 38 out of 70 students (54%) scoring above the average. Although not concluded with detailed data points, we believe the project element, performed in the second half of the semester, was effective in enhanced learning of the contents and improving the class performance in the theoretical elements in the final exam compared to the midterm.

Most of the students perceived the project as an important component of this course contributing to their learning. This conclusion is drawn from the responses to the statement "I feel the group project was an important part of the course." 17 students (33% of 51 survey participants and 24% of students) strongly agreed and

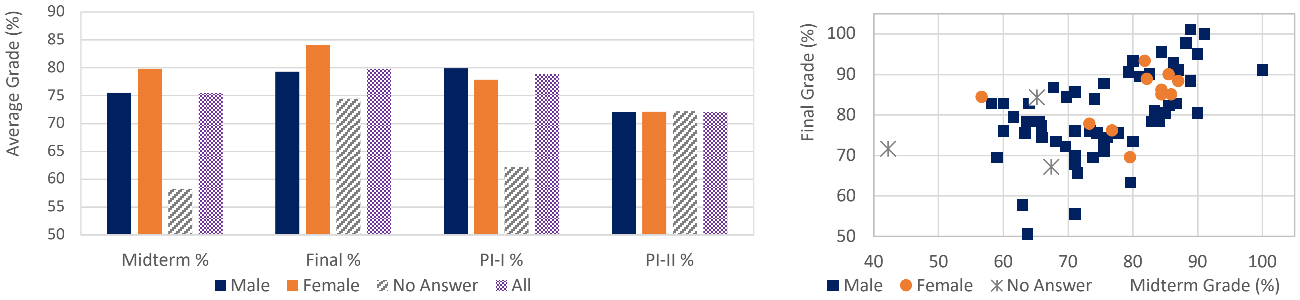

**Figure 2: (a) Average Grades as Measure of Performance (b) Grade Distribution (Midterm/Final)**

22 students (43% of 51 survey participants and 31% of students) agreed, totalling 75% of survey participants agreed with this statement. Eight students (16% of 51 survey participants and 11% of students) were neutral, two students (3.4% of 51 survey participants and 2.8% of students) disagreed, and two students (3.4% of 51 survey participants and 2.8% of students) strongly disagreed.

## 4.2 Team Dynamics

Most of the students had a positive experience working within their project teams. This was consistent throughout the Mid-Project and Post-Project surveys. During Mid-Project Surveys 36 our of 38 responding students (92% of participants) believed that their groups collaborated well in PI-I. Three out of 38 participating students indicated that they would choose a different team for their PI-II if they had the chance. 28 out of 38 respondents (72% of participants) were confident their group will perform well during PI-II.

On the Post-Project Survey we measured answers to "I feel our team worked well together", "I enjoyed working with my team", "I feel that our team communicated well", and "I feel our team resolved challenges in a fair and respectful way." 88.46%, 86.53%, 90.38%, and 92.31% of the students who responded to the survey (52 out of 70 students) reported they agree or strongly agree with these statements respectively. Figure 1 illustrates these numbers.

We asked students to indicate their gender-identity in the first step of the project. 11 students self-reported as female, and 56 as male. No other gender-identity reports, although the choice was available (we better informed our approach to gender-identity questions in later offerings, but we believe there is value to reporting the current data). We had three missing submissions for the first step of the project. We did not follow up to collect gender-identity data from students with missing submissions on the following steps.

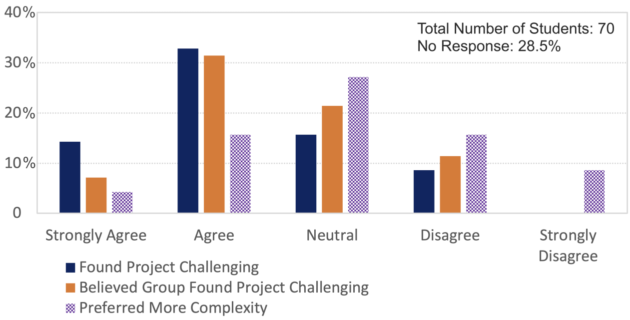

**Figure 3: Student Assessment of Challenge and Complexity**

Average of the group grade of female students in PI-I and PI-II steps of the project was 23.36 (class average: 23.32 out of 30 or 78%) and 21.64 (class average: 21.31 out of 30 or 71%) respectively. This is slightly above class average. The overall performance of these students, was 35.92 out of 45 (80%) in the midterm exam (class average: 33.47 out of 45 or 74%) and 37.82 out of 45 (84%) the final exam (class average: 35.43 out of 45 or 79%) which is considerably above average. Average grades and exam grade distributions are depicted in Figure 2. PI-I and PI-II are chosen as the technical elements of the project, and the ones with the highest grade variations.

Only four female students shared a group with another female students and that means two female students had three teammates who did not self-identify as female, and the rest of the female students had four teammates who did not self-identify as female. The students who did not self-identify belonged to different groups, and only one of them was part of a group with one self-identified female student. Therefore, all of the 14 project groups had non-female majority. While team composition does not show any negative effect on team dynamics and technical communication, we believe the performance variations across personal and group evaluations for female students needs further investigation.

## 4.3 Confidence Building

Before the start of the project, 25 students (36% of students and 63% of survey participants) reported that they are planning to use this group project in their resume. After the start of the project, also 25 students (36% of students and 48% of survey participants) reported they are planning to use the group project on their resume. However, except for 7 students who kept their initial choice, the group of the students answering this question in the Pre-Project and Post-Project questions were different. While this could be affected by different factors, our analysis of data shows correlation with complexity and specification of the project, and student perception of group's performance in the project affecting this choice.

Figure 3 shows the student perception of complexity of the project. The answers are in response to the questions "I found the project challenging", "Our group found the project challenging", and "I would have preferred to build a more complex project" respectively. An interesting observation is that the number of students who thought the project was challenging (47% of 52 survey participants) was higher than the number of student who thought their group found their project challenging (38.5% of 52 survey participants). This is while students reported great team dynamics and technical communication. Therefore, it could be used as indicator of lower self-confidence compared to the reliance on the group.

At the end of the project, 35 students (70% of respondents) believed that the project contributed to their confidence in building and deploying scalable web applications. These numbers are drawn from 9 students who responded strongly agree, and 26 students who responded agree to the statement.

## 4.4 Technical Communication

At the beginning of the project, 67 students (out of 70 students) participated in the survey. 5% of survey participants believed they need to improve their technical communication skills. 17 students (25% of survey participants) believed they have fair technical communication skills. 39 students (58% of survey participants) believed they have good technical communication skills, and 8 students (12% of survey participants) believed they have very good technical communication skills. Figure 4 depicts participants' self-assessment of technical communication skills before and after the project.

At the end of the project, 50 survey participates answered the survey, and participants who were among those who believed they need to improve their technical communication skills at the start of the project, were among those who strongly agreed with the statement that the project has improved their technical communication skills. 33 students (66% of survey participants) felt their technical communication skills have improved (agree or strongly agree). We believe project presentations, the process of peer-review for presentations, and project report template and timeline that included explicit assignments on certain team communications (team selection, group title selection, communications for each team role, workload determination) have affected this self-assessment.

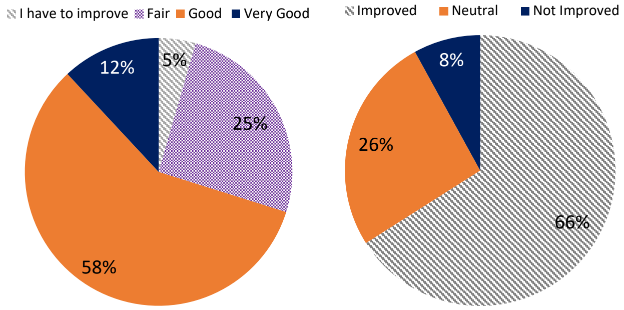

**Figure 4: Student Self-Assessment of Technical Communication Skills (a) Before and (b) After the Group Project**

## 5 CONCLUSION & FUTURE WORK

This work informed our approach to project-based learning in the group-project component of an upper-level undergraduate systems course. We believe that the group-project is a major learning component for students. This belief is based on student performance data as well as student survey results such as feedback from 70% of Post-Project Survey respondents, believing that the project contributed to their confidence in building and deploying scalable web systems. In addition, 66% of Post-Project survey respondents believed this project improved their technical communication skills.

We also believe the group project helped students form functional teams and learn together, which was especially important at the time of isolation due to the COVID-19 pandemic. This conclusion is based on the data from 52 students who participated in the Post-Project Survey: 88.46%, 86.53%, 90.38%, and 92.31% reported working well together, enjoying teamwork, communicating well, and respectful challenge resolution within their team, respectively.

Our approach for specification and scaffolding for maintaining a balance among supporting the class entirety and motivating risk-taking in project achieved the learning outcomes for the entirety of the class very well. However, it proved to result in lower risk-taking. We believe this might be due to the fact that this approach required the student groups to ***choose*** a project stream early on the project timeline. Therefore, anticipation of complex requirements in the next steps of the project might have caused the more measured choice and less risk-taking, even when it is motivated through bonus marks for additional activities.

Based on the presented results and our further research in implementation and fading [13] of scaffolding [16] [14] [18], we would like to explore the following alternative approaches in the future offerings of the course: First, we would like to consider providing faded scaffolding as an available option without asking students to choose a stream to include it. This is because we believe when students were asked to make decisions about the project stream at the beginning of their project, even though they were able to change their stream throughout the project, their choice was affected by anticipation of losing the option of having needed information in the future. Therefore, to avoid the fear of the unknown, they opted to perform the more specified projects. We implemented this approach during Fall 2021. Our preliminary results show similar specification feedback, slight improvement in project components, and an overall 15.6% improvement in SETC student learning experience feedback.

Second, to help confidence building and further motivate risk-taking, we would like to consider starting the project with a presentation, providing one excellent complete project from student groups of previous cohorts as an example for the specified technical requirements, presented with discussion of different variations the project might include in meeting the technical requirements.

Third, based on the observation on students' response on their perception of complexity versus their group's perception of complexity, and inspired by a work by Fisk et. al [7], we would like to investigate the effect of an intervention by presenting the Mid-Project survey results. We believe this can enhance perception of self-performance and confidence during the next project steps.

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