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Effective Collaborative Inquiry-based Learning in Undergraduate Computer Networking Curriculum

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Abstract

In 2010, California State University Los Angeles (CSULA) received a CCLI grant from NSF to explore a good solution to incorporate collaborative project-based and inquiry-based learning in undergraduate computer networking curriculum. The project goals include: 1) Establish a cyber-infrastructure to enable remote learning which significantly improve the learning efficiency of students on a commuter campus; 2) Foster students' hands-on design and implementation skills in networking field; 3) Improve teaching and learning efficiency by integrating project-based and inquiry-based learning pedagogy. During the past two years, an effective infrastructure has been built to support various online collaborative learning activities; and our proposed teaching strategies have been continuously improved to meet the needs of a diversified student body. The on-going project assessment shows that project-based and inquiry-based learning in networking classes has generated positive impact on students' mastery of related course concepts. Particularly, students working collaboratively in a well-established team environment tend to have a higher satisfaction in their learning and can better achieve the learning outcomes. Some of the assessment data were presented in ASEE conference last year.

In this paper, we focus to answer one question "How to effectively incorporate collaborative inquiry-based learning in undergraduate computer networking curriculum". First of all, the paper introduces a general framework derived from our best practice for integrating inquiry-based learning into the classroom that can be applied to any engineering course. Next, effective teaching strategies to implement the above-mentioned framework, such as *how to balance between theory and hands-on activities*; *how to seamlessly integrate inquiry-based learning into rigorous curriculum*; and *how to ensure student learning in open-ended inquiry-based activities*, will be presented. Concrete examples will be provided to show how to design inquiry-based projects for representative undergraduate networking topics and how to conduct them in classroom to enhance the learning of students from minority groups. The paper will also share the lessons learned through our teaching practice and project assessment, and highlight Dos and Don'ts for educators who are interested in incorporating inquiry-based learning strategy in their teaching.

Introduction

To prepare the next generation engineers to meet the demands of the fast-evolving global market, it is important to imbue the current engineering students with both good knowledgebase and strong skills to solve real-world problems and to design components or a system under realistic constraints. Recently, the engineering education community has embraced project-based learning (PBL) as an effective teaching pedagogy. As summarized by Brigid Barron and Linda Darling-Hammond [1], PBL is one of the families of inquiry-based learning approach, which allows the students to learn more deeply via applying knowledge learned in class to solve well-design problems that represent real-world scenarios. Literature study reveals many successful implementations of PBL in different engineering classrooms from freshman to senior levels [2-6]. However, it is also widely recognized that the success of PBL is heavily dependent on the way of implementation [1]. In fact, compared to the traditional classroom instruction, PBL imposes higher requirements on both instructors and students. To achieve the expected learning outcomes in PBL (or any inquiry-based learning settings), the students should have strong initiative to conduct the project, sufficient confidence to proceed and good team skills to work together. If the students lack one or more of the above skills, the implementation of PBL can be very challenging.

Since 2010, we have been redesigning our undergraduate computer networking curriculum in both Electrical Engineering and Computer Science departments by incorporating Collaborative Project-Based Learning (CPBL). This work is supported by NSF CCLI project, and it is a direct extension to our previous effort of flipping the classroom of EE244, a freshman level digital design class [7-10]. One unique feature of our current work is the creation of a sequence of scalable remote labs that integrate project-based and inquiry-based learning [11]. While providing significant benefits to students on a commuter campus like CSULA, extending project-based learning beyond the classroom also introduce unique challenges. Furthermore, as a federally designated Title III institution, CSULA has a large number of students from minority groups and low income families. Many students have low self-efficacy due to their lack of academic preparation. In the past two years, we have been continuously improving the implementation of CPBL to address the learning issues for students from minority groups. In this paper, we will share what we learned in our practice on how to effectively embed inquiry based learning through in-class and after class projects. Examples will be presented to show how to design a project to complete a natural learning cycle and strategies will be described on how to conduct remote CPBL to ensure the achievement of learning outcomes for underprepared students. Although the presented projects were developed for computer networking curriculum, the strategies can be adapted to many different engineering classroom environments. We hope our experience can benefit colleagues who are interested in incorporating inquiry-based learning strategy in their teaching practice.

The paper is organized as follows. Section 2 presents the CPBL model beyond the classrooms. Effective strategies to develop and conduct CPBL are described in Section 3, along with the case studies. Section 4 shares the project assessment results in the past two years to demonstrate the impact of CPBL, and Section 5 concludes the paper.

CPBL Model Beyond Classroom

Collaborative Project-based Learning is a specific PBL model developed by the project PI and her colleague to enhance the learning of minority students [8]. Different from typical PBL setting, CPBL is more focused on the creation of a friendly learning environment that is less intimidating to minority students. The key features of CPBL include: 1) A series of small in-class projects that are simple enough for students with limited background knowledge but collectively serve as a ladder to build up the students' design skills progressively; 2) Fostered peer-collaboration to help build up students' confidence to complete the projects; 3) Timely help and immediate feedback from the instructors. Since the peer collaboration and student-professor interaction are key to the success of CPBL, the projects are typically conducted in the class.

To extend CPBL beyond classroom, first of all a cyber-infrastructure needs to be established. At CSULA, OPNET Modeler is installed on 16 blade servers, each of which allows one student team to remotely access the software so they can work together on the projects as shown in Figure 1 [11]. However, as revealed by project assessment results, peer collaboration does not come through naturally when working remotely, hence, proper guidance from the instructor is essential to foster a collaborative learning environment. Figure 2 depicts the essential components for the extended CPBL. It shares many common features with the original CPBL; specifically, the in-class project series are designed to build up the students' design skills as well as team skills so they are prepared to do the after-class projects. Both the in-class and after-class projects are designed not only to reinforce the material learned in the lectures, but also introduce new pieces of knowledge on network simulation, design process as well as on network protocols themselves involved in the projects. The list of developed projects in EE440 and CS470 (Networking courses in Electrical Engineering and Computer Science departments) were presented in our previous ASEE publication [12].

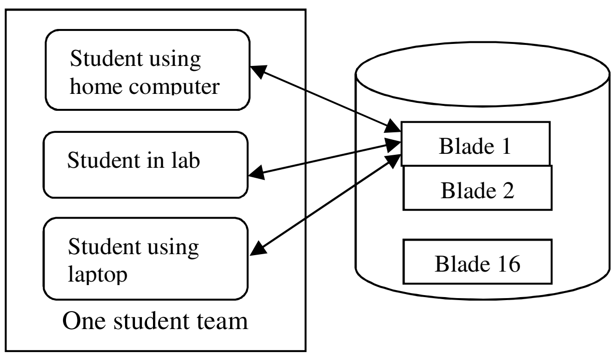


Figure 1. Online collaborative project-based learning infrastructure [].

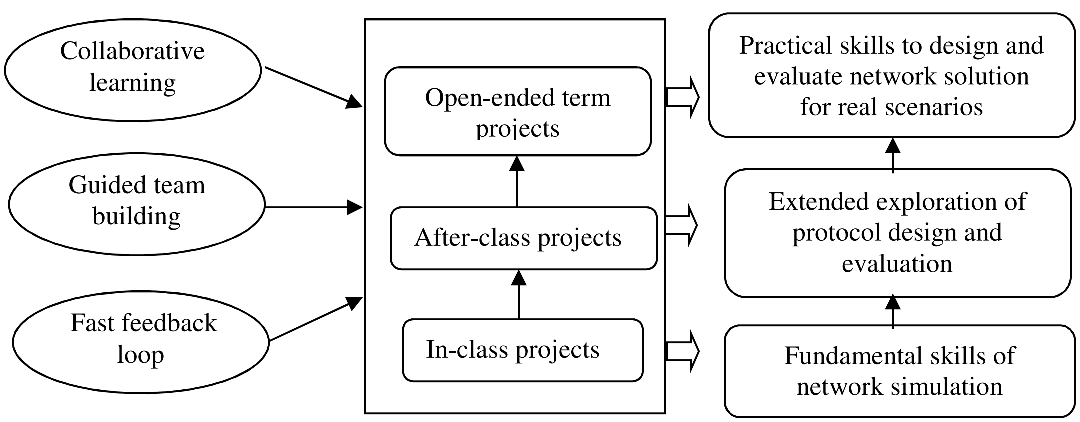


Figure 2. Essential components for CPBL beyond the classroom.

Integrating Collaborative Inquiry-based Learning using Class Projects

The core of the CPBL model is a set of well-designed in-class and after-class projects that are integrated into the curriculum seamlessly to enhance students' learning outcomes. In the extended CPBL model shown in Figure 2, projects of different scopes and complex levels were developed to build up the students' knowledge and skills step-by-step. The in-class projects are simple ones that are easy for students with limited skills to conduct. Each in-class project should be completed within a 100-min class period. Students gain basic knowledge of network simulator OPNET and develop a fundamental understanding of how to use OPNET to do network design and protocol performance evaluation. Furthermore, the in-class projects are directly tied to the content discussed in lectures, and some are used in place of lectures to introduce network concepts. Although small in scope, each in-class project is developed to contain the complete cycle of inquiry-based learning.

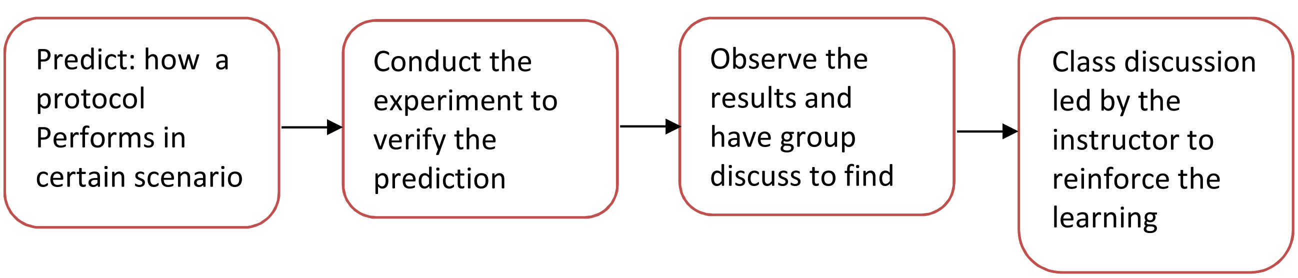
After-class projects are generally bigger in scope (median-scope projects) and require the collaboration of team members to achieve the project goals. Since after-class projects are done remotely, team collaboration can be problematic. In our implementation process, we found out that an effective way to foster peer collaboration is to have dedicated tasks for each team member while to obtain the solution all members need to put their individual work together and think collaboratively.

The term project offers an opportunity for the students to work on a real-world design problems. It is done after-class, and the strategy mentioned above is also used to ensure each team member participate in the design and obtain the expected learning outcomes. However, the term project has a larger scope, and requires the students to conduct research, come up with the design plan, implement the design, evaluate the results and propose a solution. Instructor's feedback during the process is highly recommended.

In this section, we will present a few representative projects of different scopes to show how to integrate the inquiry-learning process. Although the projects were developed in the context of computer networking subject, they also demonstrate the principle of effective project design to enhance the learning of students with diverse background.

- **In-class Project Example: Stop and Wait ARQ**

  The main goal of the project is to find out which factor affects the efficiency of stop-and-wait error control protocol, which also prompts the students to consider how to improve the design of a link layer protocol. This project was designed to provide an inquiry-based learning setting that allowed the students to explore and discover "new knowledge". The key components of the project are described in Figure 3. At the beginning of the project, the students were asked to write down their "perdition" (e.g. how transmission speed affect link utility, how errors may affect link utility). In the "predict" step, the students are encouraged to work in teams to formulate their initial thoughts based on their existing knowledge. Next, they will create scenarios to test their own hypothesis in the "Conduct" step. The simulation results will be observed and discussed among team members to summarize their new knowledge about stop and wait ARQ. In the last step, the instructor will guide the discussion to ensure correct concept is developed and also to deepen the students' understanding of the protocol.



- **Figure 3. Flow of inquiry-based in-class project**

- **After-class Project Example: TCP Congestion Control**

This project follows an in-class project "Why congestion?" from which the students already learned the factors that cause network congestion. After the in-class project, a lecture on congestion control algorithm, including slow start, congestion avoidance, fast retransmit and fast recovery, was given. To reinforce students' understanding of the algorithm and to explore factors that affect the performance of TCP, an after-class project on TCP congestion control was designed.

In this project, students were asked to build a simple network deployed with the popular FTP application. A number of scenarios were created to simulate the congestion control algorithm. The first scenario models a perfect network without any congestion while in other scenarios the network is configured to have congestion. New scenarios are built on the previous one with one more component of the congestion control algorithm enabled. Students were asked to compare and discuss simulation results of some parameters (the congestion window size and sent segment sequence number) collected from several scenarios, which enhances their understanding of the congestion control algorithm works and how the components of the algorithm affect the performance of TCP. Furthermore, students were asked to create more scenarios to explore and discuss how other factors such as the receiver window size and the timer value affect the performance of TCP.

Overall, a well-designed project should contain the following common features: 1) easy-to-follow instructions with visual help; 2) short, concise, and clear requirements; 3) inquiry-based learning components; 4) scalable activities to meet the needs of students with different backgrounds; 5) team discussion and/or faculty guided class discussion to reinforce the learning.

Effective Implementation Strategies

The implementation of CPBL is gauged carefully via project assessment. Although the overall assessment findings are positive, challenges still exist to make the online collaborative PBL effective to all students with different backgrounds. In this section, we would like to share the lessons learned in our own implementation process and highlight a few effective strategies to maximize the positive impact of CPBL with inquiry-based learning components on students' learning.

Effective Team Building is Key to Successful Remote CPBL
Community inquiry is an essential component in inquiry-based learning. In the remote CPBL model, students are required to work in teams, not only to complete the project, but also to think collectively to gain new knowledge. However, based on our observation, effective collaboration does not come through naturally especially for students lacking initiative and self-efficacy. Hence, it is important for the instructor to apply team building strategy to foster effective collaboration. Our developed team building strategy contains 1) provide guidelines to create project teams with students of diverse background and help to identify roles of each member in the team; 2) devise policy for a team to share the use of a blade; 3) help teams to identify ways to

maintain close communication among team members when working on remote projects; 4) periodically assess the progress of team building throughout the quarter. In addition, it is also helpful for the instructor to develop projects with components that need to be completed by different team members along with exploratory questions or tasks that require collective efforts of the team.

Seamless Integration of Projects into Curriculum

The balance between direct instruction and hands-on projects/inquiry-based learning activities always presents a challenge for implementing CPBL in a tight 10-week teaching schedule. In our implementation process, we realized that it is important to develop class projects in a way that each of them also delivers some of the theoretical contents to save the lecture time. Nevertheless, it is a challenging task for the instructor. On one hand, each project needs to be designed to convey a good learning process; on the other hand, the instruction needs to be carefully planned to ensure that the students have pre-requisite knowledge to conduct the projects and achieve the expected learning outcomes. One bitter lesson learned from our practice is:"Don't be too ambitious when designing in-class projects." The scope of the in-class projects has to be small enough for most of the students to complete within a class period. It is noticed that even if the project content was designed to deliver a theoretical concept clearly, the students who struggled with completing the projects in time may not be able get it.

Better Support for Visual Learners and On-line Learning Community

For under-prepared students, it is crucial to provide timely support when they are working on the projects. While immediate help is available for in-class projects, similar support should be offered to student teams for after-class projects as well. During the 2nd project year, we have made significant efforts to develop online tools including one-minute tutorial video clips and online FAQ to help construct an online learning community to better support students in their project experience. Specifically, the one-minute video demo that teaches how to use OPNET and how to troubleshoot common errors were very well received by our students. Many students reported that they were visual learners that responded slowly to written instructions in text, but could learn much better with visual demo. To help all students achieve expected learning outcomes, it is important to recognize and honor the various learning styles of different students and provide diversified learning tool to help them succeed.

Impact on Student Learning

The assessment data collected in the past two years verified that integrating CPBL in the curriculum generated positive impact on student learning. In addition, the inquiry-learning components helped to stimulate the students' interest in computer networking field. More details of formative assessment can be found in our previous ASEE paper [12], and this section summarizes the 2-year summative assessment results to demonstrate the impact of CPBL in student learning.

The two computer networking courses at undergraduate level that were revised to integrate CPBL model are CS470 and EE440. In each quarter when either of these courses is offered, we use pre and post surveys along with focus groups to measure the growth of students' knowledge and skills both quantitatively and qualitatively.

Table 1 lists the knowledge outcomes evaluated via pre and post surveys in CS470 and EE440. Usually, the pre survey is conducted at the beginning of quarter and the post survey is conducted at the end. The difference in the survey scores is used to indicate the students' self assessment on their knowledge/skill change. In the table, outcomes with * are directly reinforced by in-class or after-class projects.

Table 1. Knowledge sets evaluated via pre and post surveys in CS470 and EE440.

Index	*Knowledge Outcomes in CS470*	*Knowledge Outcomes in EE440*
K-1	Knowledge of network design process	Knowledge of network design process
K-2	Knowledge of network simulation*	Knowledge of network simulation*
K-3	Knowledge of network performance analysis*	Knowledge of network performance analysis*
K-4	Knowledge of layered network architecture	Knowledge of data communication model
K-5	Knowledge of network topology (bus, star, etc.)	Knowledge of layered network architecture (OSI and TCP/IP model)
K-6	Knowledge of IP addressing and subnetting	Knowledge of various data encoding technologies (NRI, Manchester coding)
K-7	Knowledge of Internet routing	Knowledge of network topology (bus, star, etc.)*
K-8	Knowledge of ARQ and TCP error control*	Knowledge of ARQ*
K-9	Knowledge of TCP flow control and congestion control*	Knowledge of Ethernet.
K-10	Knowledge of DNS, SMTP	Knowledge of how to build and extent a Local Area Network using bridge
K-11	Knowledge of HTTP and FTP	Knowledge of CSMA/CD*
K12	Knowledge of OPNET Software*	Knowledge of OPNET Software*

Table 2. Impact of CPBL on student knowledge growth (pre and post survey analysis).

Outcomes	*CS470 (2011)*			*CS470 (2012)*			*EE440 (2011)*			*EE440 (2012)*		
	Pre	*Post*	*diff*	*Pre*	*Post*	*diff*	*Pre*	*Post*	*diff*	*Pre*	*Post*	*diff*
K-1	2	3.7	1.7	2	4.11	2.11	2.72	4.27	1.55	2.05	4.40	2.35
K-2	1.6	3.5	1.9	1.65	4.33	2.68	2.07	4.18	2.11	1.62	4.63	3.01
K-3	1.5	3.4	1.9	1.65	3.89	2.24	2.34	4.27	1.93	1.81	4.67	2.86
K-4	1.9	3.9	2	1.87	4.33	2.46	2.45	4.45	2	1.52	5.00	3.48
K-5	2.1	3.9	1.7	2.12	4.22	2.1	2.52	4.27	1.75	1.65	4.56	2.91
K-6	2.7	4	1.3	2.23	4.67	2.44	2.21	4.82	2.61	1.35	4.86	3.51
K-7	2.6	3.9	1.3	1.84	4.44	2.6	2	4.55	2.55	1.67	4.22	2.56
K-8	1.4	3.7	2.3	1.58	4.44	2.86	2.45	4.36	1.91	1.28	4.11	2.83
K-9	1.7	3.8	2.1	1.35	4.11	2.76	2.83	4.36	1.53	2.38	4.63	2.24
K-10	2	3.8	1.8	2.78	4.44	1.66	2.31	4.18	1.87	1.86	4.57	2.71
K-11	2.6	3.9	1.3	2.67	4.44	1.77	1.83	4.36	2.53	1.19	4.75	3.56
K-12	1	2.8	18	1.12	3.44	2.32	1.76	4.09	2.33	1.24	4.44	3.21

Table 2 shows the 2-year results of pre and post surveys to indicate the knowledge growth. In the survey, students ranked their knowledge using the sets listed in Table 1 (1- "None", 2- "poor", 3- "Fair", 4- "Good", 5-"Excellent"). Clearly, all knowledge outcomes received much higher scores in post survey and in general we can observe a greater growth in year 2012, which reflected the effect of improved implementation of CPBL in the 2nd project year. Analysis of two year data consistently proved that most of the biggest growths occurred in the learning outcomes directly related by the class projects. For example, in CS470 offered in Winter 2012, the biggest increments of the rating occur on the following outcomes, and all of them are directly addressed by in-class or after-class projects.

- Knowledge of ARQ (Pre=1.58, Post=4.44, growth=2.86)
- Knowledge of TCP flow control and congestion control (Pre=1.35, Post=4.11, growth=2.76)
- Knowledge of network simulations (pre=1.65, Post=4.33, growth=2.68)

Similarly, in EE440 offered in Spring 2012, the following are outcomes that exhibited significant growth (difference of the pre and post survey scores are more than 3):

- Knowledge of CSMA/CD (Pre=1.19, Post=4.75, growth=3.56)
- Knowledge of various data encoding technologies (NRI, Manchester coding) (Pre=1.35, Post=4.86, growth=3.51)
- Knowledge of Shannon Theory (Pre=1.52, Post = 5, growth=3.48)
- Knowledge of OPNET Software (Pre=1.24, Post = 4.44, growth=3.2)
- Knowledge of network simulation (Pre=1.62, Post = 4.62, growth =3)

Among the above 5 biggest growths, three of them were reinforced by OPNET project experience.

Now, let us take a look at the impact of CPBL on the development of students skills. Table 3 lists all skill outcomes, while table 4 summarizes the 2-year pre and post survey data on skill growth. In fact, it is more obvious that the greatest growth happened in those skills that were directly addressed by the CPBL experience.

Table 3. Skill sets evaluated via pre and post surveys in CS470 and EE440.

Skill Outcomes in EE440 and CS470	
General Skills	Specific Skills related to OPNET projects
S-1. General computing skills	S-6. Ability to design and implement a network scenario in OPNET
S-2. Communication skills	S-7. Ability to analyze the network performance using simulations
S-3. Math skills	S-8. Ability to choose an optimal design based on realistic constraint
S-4. General design skills	S-9. Ability to use OPNET to explore and learn new network protocols
S-5. Computer network design skills	

Table 4. Impact of CPBL on student skill growth (pre and post survey analysis).

Outcomes	*CS470 (2011)*			*CS470 (2012)*			*EE440 (2011)*			*EE440 (2012)*		
	Pre	*Post*	*diff*	*Pre*	*Post*	*diff*	*Pre*	*Post*	*diff*	*Pre*	*Post*	*diff*
S-1	3.7	4.5	0.8	4.45	5	0.55	4.34	4.75	0.41	3.57	4.43	0.86
S-2	3.5	4.1	0.6	4.23	4.56	0.33	4.07	4.64	0.57	3.52	4.33	0.81
S-3	3.6	3.9	0.3	4.55	4.89	0.34	4.34	4.73	0.39	3.67	4.33	0.67

S-4	3.3	3.9	0.6	4.32	4.78	0.46	3.83	4.64	0.81	3.14	4.11	0.97
S-5	2	3.7	1.7	1.12	4.11	2.99	2.66	4.36	1.7	2.00	4.13	2.13
S-6	1.3	3.6	2.3	1.12	4.11	2.99	2.17	4.73	2.56	1.38	4.25	2.87
S-7	1.3	3.6	1.3	1.12	4	2.88	2.03	4.82	2.79	1.45	4.50	3.05
S-8	1.3	3.7	2.4	1.12	3.56	2.44	2.41	4.64	2.23	1.71	4.25	2.54
S-9	1.2	3.6	1.4	N/A	N/A	N/A	1.9	4.55	2.65	1.24	4.00	2.76

Overall, the multiple pre and post survey results demonstrated that CPBL is effective to enhance the students' understanding on key theoretical concepts and also help to develop students' hands-on skills in network simulation, design and performance analysis.

In addition to the pre and post surveys, focus groups were continuously hosted throughout the project duration to collect students' feedback and suggestions. The focus groups were facilitated by our external evaluator, a Professor in College of Education, who used open-ended questions to probe students' feedback on course material, instruction, and their learning experience. The qualitative data from the focus group conducted in various quarters are consistent. Overall, the results highlighted the value of integrating hands-on practice with inquiry-based learning components using CPBL. In all focus groups, majority of the participating students stated that the project experience made them more interested in computer networking fields. The following is a list of "what the students like" about CPBL beyond the classroom:

- The ability to work on OPNET projects remotely from any location and the flexibility to work with their own time and paces are extremely valuable to students on a commuter campus
- Great balance between theory and practice
- The fact that multiple people can access the blade server together and work on the project as a team
- The term project was the most favorite one as it was very involved and provided opportunity to do open-ended design and be creative

The open discussion in the focus groups also allowed us to collect students' concerns and identify potential problems in the implementation process. Two main issues identified via focus groups are: 1) difficulty in peer collaboration in remote settings; and 2) insufficient time to complete in-class projects. The students' feedback prompted us to improve the design of our in-class projects and also develop corresponding strategies to enhance peer collaboration. The detailed strategies were presented in the previous section.

Conclusions and Future Work

This paper focuses to answer "How to effectively incorporate collaborative inquiry-based learning in undergraduate computer networking curriculum". Specifically, inquiry-based learning is embedded in the hands-on in-class and after-class projects to allow students to extend their understanding of course materials and discover "new knowledge" following a natural learning process. Through concrete examples, principles of how to develop class projects to engage students in inquiry-based learning process are introduced. Furthermore, strategies to implement CPBL are presented to address the learning issues of students from minority groups. Multi-year summative assessment data were presented to demonstrate the impact of CPBL in student learning outcomes. In the future, the PIs will enhance the online learning community by developing more visual tools and enrich the online FAQs. After comprehensive classroom testing, the developed projects and online tools will be widely disseminated to benefit a broader learning community.

Acknowledgment

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