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Improving Graduate Engineering Education through Communities of Practice Approach: Analysis of Implementation in Computer Science, Robotics, and Construction Engineering Courses

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Abstract

This work-in-progress paper reports early results of implementing Communities of Practice (CoP) as a theoretical framework for designing, evaluating, and redesigning three highly interactive graduate engineering courses. This NSF-funded research project studies whether and how students in the courses bridge the gap between university and professional engineering work, establish collaborative partnerships with other students and professional communities, and navigate multiple-team collaboration in a complex setting. These courses allow us to study how students with different backgrounds, knowledge, and skills work in highly collaborative environments, which emulate professional engineering CoPs. This work uses class observations, interviews with former and current students and the professionals they interact with surveys, and class materials to analyze and improve these three courses. Using these data resources, we analyze how CoPs form, how CoPs in different disciplines learn to interact and collaborate, what conditions foster equitable participation by all members of a CoP, and what are some best practices, heuristics, and guidelines for effective academic CoPs. Additionally, we advance CoP theory and methods, by describing existing CoP concepts such as Legitimate Peripheral Participation (LPP) in novel contexts, describing disconnection between communities, and developing interview protocols and social network analysis methods to interpret and evaluate CoP experiences among students and professionals. This paper highlights minority students' experiences regarding barriers to their participation in engineering communities and identifies which tools and approaches can be used for effective evaluation of CoP experiences in a classroom environment. Instructors of other engineering courses can adopt the results of this work.

Introduction

Policy documents from around the world highlight the need for graduate STEM students with strong collaborative skills in multidisciplinary environments (European Commission, 2018; Education Services Australia, 2018; World Economic Forum, 2017, National Academies of Science, 2018; National Science Foundation, 2020). Despite this emphasis, however, existing efforts, as documented by the US-based National Academies of Science, are still insufficient to meet the need (National Science Board NASEM, 2018). In the field of engineering, for example, the Institution of Engineers Australia showed there is a gap between employers' expectations and engineers' skills: "While the existence of a persistent skills shortage is difficult to quantify, it is clear that Australia is facing an engineering skills disparity that needs to be addressed" (Bell & Briggs, 2022, p. 16). This skills shortage and the high expectation of employers create high pressure that generates anxiety and stress when recent graduate experiments join a company (Jackson, 2014; Kolmos & Holgaard, 2019).

In this project, we iteratively study three highly interactive courses which are designed to address the industry's calls for improving graduate engineering education. We analyzed students' work in the courses as well as their attitudes and outcomes and then redesign the courses to incorporate improvements based on the data analysis. Indeed, by collecting multiple data sources (interviews, course evaluations, surveys, class observations, etc.), this project aims to identify some essential pillars to designing an effective graduate engineering class. To interpret and analyze those three collaborative environments, this project uses the Community of Practice (CoP; Lave & Wenger, 1991, Wenger 1998) theoretical framework. As Lave & Wenger (1991) stated, " In our view, learning is not merely situated in practice, as if it were some independently reifiable process that just happened to be located somewhere; learning is an integrated part of generative social practice in the lived-in world" (Lave & Wenger, 1991, p. 35). However, this promising framework faces challenges in being fully implemented in a formal academic setting. For example, our early results showed the lack of tools that instructors can use to measure the effectiveness of CoP in an academic setting (Díaz et al., 2022b, Díaz et al., 2023b). CoP-based surveys that were developed in other contexts, like the Community Assessment Toolkit (CAT: Verburg & Andriessen, 2006), were not appropriate to use in graduate engineering students, while other methodologies rely heavily or exclusively on time-consuming qualitative research methods (Díaz et al., 2022b). Taking those challenges, this project aims to investigate three highly interactive graduate engineering classes. The following sections discuss why those three courses are relevant, how they are connected, and how the CoP framework can help to describe and evaluate them.

Educational Data Mining (EDM).

EDM is offered in the Department of Computer Science but is open to students from education. The class uses project-based learning, with students working on individual tasks and forming teams of 2-3 members to work on a larger-scale project suitable for publication. The course represents a large community of practice with each team acting as a sub-community. Students can support other teams' projects; however, cross-team collaboration is not an expectation. This type of setting (a one-class community with multiple sub-independent communities) is one of the most common or traditional in collaborative engineering classes. This course will help us to understand how students with two different backgrounds (educational and computer science) negotiate their participation, adapt their language, and bring their knowledge, skills, and object to the new community, and whether and how students emerge as "brokers" (Wenger, 1998) that help disseminate ideas and tools across the disciplinary communities.

Building Information Modeling in Construction (BIM)

This course is offered for graduate students from the civil engineering department. Students engage in an internship where they must work on a real construction project implementing BIM technologies. This class has the interaction of two large communities (the university and the construction company). Students must transfer their knowledge and skills from the classroom to the companies and, potentially, from the companies to the classroom. Using a CoP lens, students may develop brokerage skills by transferring objects, tools, procedures, terminology, and ideas from one CoP to another. This course led us to understand how two communities can effectively establish a partnership that creates a bridge across two different contexts.

Design of a Robotic Computer Vision System for Autonomous Navigation (Robotic)

Robotics is a graduate-level class for students in electronics, construction, computer science, and electrical engineering. The entire class is challenged to design and build a robot with an autonomous navigation system. Students are split into teams based on their previous academic interests or work experience background. Every team is in charge of one component of the robot (e.g., the arms team or hardware team); however, across teams, collaboration is needed to ensure all subsystems are implemented in a single robot. In terms of CoP, the entire class is a CoP, and every team forms a sub-community. The distinguishing characteristic of this course is there are strong dependencies between teams. This course helped us to understand how CoP principles can be used to emulate real engineering environments where multidisciplinary collaboration is needed.

Research Questions

1) How does applying CoP principles in graduate engineering courses impact student perceptions of class effectiveness and preparation for professional engineering work?
2) How do members of traditional engineering groups perceive the contributions of members of underrepresented groups in their CoPs, and (how) do they think about and act to build psychological safety in their CoPs?
3) How do academic CoPs function? What are some best practices, heuristics, and guidelines for effective academic CoPs?

Methods

This study was conducted in a large public research university in the Southeastern United States and is a collaboration between the departments of Civil Engineering, Computer Science, and STEM Education. The project researchers teach the courses.

Participants (EDM)

EDM is offered every Spring semester. Around 30 engineering master’s and doctoral students participated. Most students are from computer science departments; however, this course is also open to graduate students from the College of Education. Historically, one or two students have an educational background, and others have a computer science background. All students in the class will be invited to participate in this research project. Invitations will be emailed, and researchers will be in person to invite students to participate in the research.

Participants (Robotic)

This course is offered every Spring semester. Around 20 engineering master’s and doctoral students participated. Students were from the departments of Electrical and Computer Engineering (ECE), Computer Science (CS), and Civil Engineering (CE). Historically there is high male participation (more than 75% of the class) and a high diversity of race/ethnicity of the students. Indian male students are the most representative group historically in the class. All students in the class will be invited to participate in this research project. Invitations will be emailed, and researchers will be in person to invite students to participate in the research.

Participants (BIM)

This course is offered to graduate engineering students (master's and Ph.D. level). The course is offered every year in the Fall (except the year 2020 due to Covid). Every year it receives about 20-30 students. Most of the students are in construction or civil engineering programs. All students in the class will be invited to participate in this research project. Invitations will be emailed, and researchers will be in person to invite students to participate in the research.

Instruments

The only quantitative instrument to evaluate the functionality of a Communities of Practice identified in the systematic literature review conducted by Mckellar (2014) and our own literature review was Verburg and Andriessen's (2006) Community Assessment Toolkit (CAT). The reliability of each of the 17 sections of the CAT (each consisting of 2-8 items) was assessed by calculating Cronbach's alpha and found to be acceptable, based on data from 277 participants of 7 different CoPs in a large multinational corporation. However, there is no discussion of the validity of the test, and some sections are unrelated to CoP theory (e.g., information and communication technology).

In terms of collaboration, prior research has established that highly diverse CoPs have the best and most innovative performance when members feel psychologically safe. Edmondson (1999) developed the Team Learning and Psychological Safety Survey. The survey's validity and reliability were established through Cronbach's alpha and factor analyses; the paper presenting the survey has been cited over 10,000 times.

Considering the lack of instruments, we developed interview protocols and course evaluation surveys using the main concept of the CoP framework. In our previous work (Díaz et al., 2022a), we discussed that the result of this pilot concluded that CAT is not appropriate for use in our context. Additionally, TLPSS, course evaluation, and protocol are useful for evaluating the impact of courses.

Data Collection

The methods for all three courses are broadly similar and consist of the following.

Multiple student interviews. All students were invited to participate in interviews. There were two interviews, one in the middle of the course and another at the end. Interviews will be around 20-40 minutes using ZOOM. The interviews will be semi-structured and guided by a protocol.

Team Learning and Psychological Safety Survey. The TLPSS survey was applied to all students at the beginning and middle of the course. The survey was administered electronically using Qualtrics (www.qualtrics.com).

Multiple class observations. In all classes, a researcher recorded observations of participation, communication in the class, dynamics, and students' progress. In the first class, the researcher introduced himself to all students. From the observation, a memo was developed per class.

Class material. The materials generated within the course were analyzed. For example, students' weekly presentations and mid-term and final reports were used in the analysis. Those documents provide a summary of students' progress, problems faced by students, and a full description of the project's task.

Results

Pilot-Testing the Instruments

To evaluate the accuracy and applicability of the instruments selected in the literature (CAT & TLPSS) and the instruments we developed (interview protocol & course evaluation), these were initially piloted. Pilot testing involves using the research instrument on a sample similar to the study participants before its full-scale use (Baker, 1994). Pilot testing aims to assess whether the instrument may be inadequate or too complicated and identify logistical obstacles for training purposes (van Teijlingen and Hundley, 2002). Using think-aloud interviews, the CAT instrument was not effective in our students because it was confusing for students. The TLPSS, interview protocol, and course evaluation were found effective for our context (Díaz et al., 2022b). Consequently, CAT will not be included in our research.

Methodology development for evaluating multiple teams collaborations

In our recent work (Díaz et al., 2023a, Díaz et al., 2023b), we developed a methodology to evaluate collaboration using social network analysis. We used data from the messages exchanged over Slack, which the instructor urged students to use as their main form of communication and collaboration. From this analysis, we can establish participation, interaction, communications, and collaboration parameters within and across teams. Those quantitative parameters are used to distinguish the level of collaboration of each student in the class, characterize the function of each group, analyze how groups interact, and describe the whole-course functioning based on our novel four-level framework for contexts with within- and cross-group collaboration. This methodological approach will be used with the spring 23 version of the robotic class. We are expecting to have findings to share at the conference.

Early findings from the project implementation.

In the Fall of 22, we implemented the second version of BIM in construction. From this early data analysis, we used CoP concepts to refine the role of students, instructors, and companies. For example, we propose to define the value of those strategies supporting the “learning and teaching bridge where students develop *brokers*' capacities through the reinterpretation and transfer of expertise from companies to universities by practicing vital *boundary objects*.” (Diaz et al., 2023b).

Additionally, we found that the BIM in construction course students develop bidirectional broker capacities. In fact, the course offers an effective bridge where students can transfer knowledge and tools from the company to the course and vice versa. For example, by participating in the companies, students learned how drones could be used to track progress, which was presented to other classmates. By working in the company, students learn this new technology that complements the curriculum goals. Complementarily, students propose and teach companies to implement software for coordination that they learn in class. The student’s idea was implemented first for the local company involved in the course, but then it was implemented at a national level where projects that the company involved are using this coordination software.

Interestingly, those companies’ benefits appear 2 or 3 years after participating in the BIM class. Construction projects usually take 2 or 3 years, and project managers are skeptical about implementing changes during this time. However, we found that companies take advantage of implementing students' ideas for their next project. Consequently, we encourage universities and companies to establish medium-long-term agreements and evaluate the impact of this partnership with a longitudinal perspective.

Conclusions & Future Work

As a synthesis of the three different settings under study, we have found five key aspects to successfully implementing CoP to improve graduate engineering education.

1) CoP environments need to be safe spaces, both psychologically and physically. Students should feel free to ask questions, share their ideas and interact with all members. Physical safety at construction sites is paramount.
2) The project's design should be built based on previous students' experiences. Students with more experience working in teams and knowledge of discipline are expected to assume a more active leadership role. Students must perceive the activities as a challenge and an opportunity to learn to use new *boundary objects*.
3) Stakeholder involvement (e.g., of companies) should provide a way for students to become full participants. They must feel free to participate and become an insider member of those communities.
4) The class environment should provide different levels of participation, and students should have some sponsorship or support to help them to integrate and negotiate their participation. Instructors in the classroom should carry out this role; however, companies should provide a similar member/role if students are in the workplace.
5) Universities and stakeholders must establish common principles for the management protection or sensitive information. For example, sensitive information could be budgets, subcontractor information, timelines, etc. Students must be aware of what procedures to follow to access and safeguard information.

None of our analyses has shown evidence of barriers or specific obstacles to participation associated with students' demographic information. For example, the demographic characteristics of the most and least involved students in some classes were nearly identical. Our research problematized the very concept of "under-represented" students, as many of the students in some of the courses would be minority students in the US as a whole and even engineering more broadly, but are the majority group in that specific field. We also explored whether different students' preparation could influence their participation. However, results showed that the students' participation in the class and their team are unrelated to their academic background. In Spring 23, we are collecting data from the second implementation round of EDM and Robotics. At the conference, we are expecting to present those results.

References

Baker, T., L. (1994). *Doing social research* (2nd edn.). New York: McGraw-Hill Inc.

Bell, M. & Briggs, P. (2022, March). *Engineering skills supply and demand.* Institution of Engineers Australia. https://www.engineersaustralia.org.au/sites/default/files/2022-03/Engineers-Australia-Skills-Discussion-Paper-20220310.pdf

Díaz, B. Delgado, C., Lynch, C., Han, K. (2023a, in press). U*sing mix-method to evaluate the functioning of an engineering class with multiple collaboration groups*. The International Society of the Learning Sciences (ISLS) 2023

Díaz, B., Delgado, & Han, K. (2022a, August), *BIM: A Bridge to Promote Industry-Academic Partnership in Construction Engineering* Paper presented at 2022 ASEE Annual Conference & Exposition, Minneapolis, MN. https://peer.asee.org/40995

Díaz, B., Delgado, C., Han, K., Lynch, C. (2022b, August). *Use of Communities of Practice to Analyze and Improve Graduate Engineering Education* Paper presented at 2022 ASEE Annual Conference & Exposition, Minneapolis, MN. https://peer.asee.org/40996.

Díaz, B., Delgado, C., Bacher, J., Lynch, C., Han, H. (2023b, under review). Analyzing the functioning of a graduate engineering class with multiple collaborating groups using the lens of Communities of Practice.

Education Services Australia (2018). *Optimising STEM industry-school partnerships: Inspiring Australia's next generation*. Final Report. Education Services Australia.

Engineering Council UK (2020, August). *The UK Standard for Professional Engineering Competence and Commitment (UK-SPEC)*. Fourth Edition implemented by 31 December 2021. https://www.engc.org.uk/media/3877/uk-spec-v12-web.pdf

European Commission (2018, May). *Council recommendation on key competences for lifelong learning.* (No. JRC120911). Adopted at the 3617th European Union Council meeting. https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CONSIL:ST_9009_2018_INIT&from=EN

Jackson, D. (2014). Factors influencing job attainment in recent Bachelor graduates: Evidence from Australia. *Higher Education*, *68*(1), 135–153. https://doi.org/10.1007/s10734-013-9696-7

Kolmos, A., & Holgaard, J. E. (2019). Employability in engineering education: Are engineering students ready for work? In S. H. Christensen, B. Delahousse, C. Didier, M. Meganck, & M. Murphy (Eds.), *The Engineering-Business Nexus* (Vol. 32, pp. 499–520). Springer International Publishing. https://doi.org/10.1007/978-3-319-99636-3_22

Lave, J., & Wenger, E. (1991). *Situated Learning: Legitimate peripheral participation* (1st ed.). Cambridge University Press. https://doi.org/10.1017/CBO9780511815355

McKellar, K. A., Pitzul, K. B., Yi, J. Y., & Cole, D. C. (2014). Evaluating Communities of Practice and knowledge networks: A systematic scoping review of evaluation frameworks. *EcoHealth*, *11*(3), 383–399. https://doi.org/10.1007/s10393-014-0958-3

National Academies of Sciences, Engineering, and Medicine (2018). *Graduate STEM education for the XXI century*. Alan Leshner, Layne Scherer (Eds.). The National Academies Press. https://10.17226/25038.

National Science Foundation (2020*). STEM Education for the Future: A visioning Report*. Alexandria, VA: National Science Foundation.

Van Teijlingen, E., & Hundley, V. (2002). The importance of pilot studies. *Nursing Standard (through 2013)*, *16*(40), 33.

Verburg, R. M., & Andriessen, J. H. E. (2006). The assessment of communities of practice. *Knowledge and Process Management*, *13*(1), 13–25. https://doi.org/10.1002/kpm.241

Wenger, E. (1998). *Communities of practice: Learning, meaning, and identity*. Cambridge university press.

World Economic Forum. (2017). *Accelerating workforce reskilling for the fourth industrial revolution: An agenda for leaders to shape the future of education, gender and work*. World Economic Forum, Geneva, Switzerland.