Teaching Team Collaboration in Cybersecurity: A Case Study from the Transactive Memory Systems Perspective

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***Abstract*—Recent trends in the cybersecurity workforce have recognized that effective solutions for complex problems require collective efforts from individuals with diverse sets of knowledge, skills, and abilities. Therefore, the growing need to train students in team collaboration skills propelled educators in computer science and engineering to adopt team-based pedagogical strategies. Team-based pedagogy has shown success in enhancing students' knowledge in course subjects and their motivation in learning. However, it is limited in offering concrete frameworks specifically focusing on how to teach team collaboration skills. As part of an interdisciplinary effort, we draw on Transactive Memory Systems Theory—a communication theory that explains how individuals in groups learn who knows what and organize who does what—in developing a Team Knowledge Sharing Assignment as a tool for student teams to structure their team collaboration processes. This paper reports a result of a case study in designing and facilitating the assignment for cybersecurity students enrolled in a scholarship program. Students' evaluations and the instructor's assessment reveal that the assignment made a positive impact on students' team collaboration skills by helping them successfully identify their team members' expertise and capitalize on their team's knowledge resources when delegating functional roles. Based on this case study, we offer practical suggestions on how the assignment could be used for various classes or cybersecurity projects and how instructors could maximize its benefits.**

***Index Terms*—Team Collaboration, Transactive Memory, Knowledge Sharing, Cybersecurity, Computer Science Education, Engineering Education**

I. Introduction

Team collaboration skills have been identified as one of the top competencies that prepare college students for a successful transition into the workplace [1]. Accordingly, college educators across disciplines have incorporated collaborative learning in their pedagogy and revealed its positive impact on student's academic achievements [2], [3]. The field of computer science education is no exception. Educators in computer science have recognized the growing needs for student competency in collaborative environments and have incorporated a variety of pedagogical practices into computer science education [4], [5].

Recent empirical research and case studies on team-based learning in computer science and engineering classes have shown strong positive impacts of team-based projects and assignments. While they demonstrate robust findings on how team-based learning helps students better understand and apply theories and concepts related to course subjects, little is known about the types of pedagogical practices that better facilitate students' growth in team collaboration skills in the cybersecurity context. One of the critical aspects of team collaboration is the extent to which team members are able to recognize each other's unique knowledge, skills, and abilities and leverage each member's strengths for collective performance. Therefore, the pedagogical practices that facilitate such knowledge sharing processes in student teams are likely to enhance students' team collaboration skills.

In this paper, we report a case study on the implementation of a team knowledge sharing assignment developed for computer science students enrolled in a cybersecurity scholarship program during 2019-2020 and its impact on students' team collaboration skills. In developing the assignment, we draw on the existing research on team communication, specifically team knowledge sharing literature. This case study exemplifies cross-disciplinary efforts that connect team communication research to computer science education.

II. Related Work and Theoretical Foundations

A. Pedagogical Practices for Teaching Teamwork

There are several conceptual frameworks that guide pedagogical practices related to students' teamwork. One of them is Team-based Learning (TBL), which is a pedagogical strategy that engages student teams in applying class concepts to problem solving and developing student teams' autonomy in their learning processes [3]. TBL model offers structured instructional practices that guide student's learning, including creating permanent student teams throughout the semester, engaging students in both individual and team levels in learning course contents, developing students' critical thinking skills by carefully designing team assignments and activities, and incorporating peer feedback sessions [6]. TBL model has seen much success in promoting student engagement [7], helping students develop deeper understanding of course concepts [8], and developing students' competencies that are difficult to cultivate through lecture-based instructions [9].

Similarly, Process Oriented Guided Inquiry Learning (POGIL) provides an evidence-based framework focusing on interactive and constructive instructional approaches in which students as a team participate in activities that guide them to construct their own learning as well as enhance their teamwork, communication, and problem solving skills [10]. Compared with the traditional lecture-based approaches, POGIL has been found to lower student attrition rates [11] and enhance the level of student engagement [12].

Both TBL and POGIL models offer useful frameworks for how student teams could be established as a primary learning unit in the classroom and how team-based activities produce positive impacts on student's learning and engagement for course subjects. However, they are limited in explicating how students could organize themselves and structure their internal team processes to perform team tasks effectively. In fact, instructors who adopt the POGIL model in computer science classes report that one of the biggest challenges in using the POGIL model is managing unequal participation among students and establishing clear roles and responsibilities [13]. To further articulate the design of team activities that can be incorporated into TBL or POGIL models, particularly to enhance student teams' role structures and knowledge sharing, we draw on team communication research, specifically Transactive Memory Systems (TMS) theory.

B. Transactive Memory Systems Theory

TMS is a cognitive map of who knows what and who does what in work teams. TMS theory explains that by establishing unique areas of expertise and corresponding responsibility for each individual, a collective can build a larger cognitive pool than any single individual and afford its members a heuristic value of division of labor [14]. The positive impacts of TMS on team performance are possible when team members accurately recognize each other's expertise and strengths, align individual's areas of expertise with their actual roles and responsibilities, and converge into a shared understanding about members' expertise and their roles.

While TMS theory and its empirical studies are primarily contextualized in and applied to work teams in organizations, we argue that the theory could serve as a useful conceptual framework for team-based pedagogy, particularly in the field of computer science education in which students as a team are often required to collaborate on problem-solving projects by leveraging each other's knowledge resources. When developing the team assignment in Section IV, we ground our key principles of team collaboration on this theory.

III. Background for Assignment Implementation

A. CWSSP Cybersecurity Program and the Teamwork Focus

We implemented and facilitated the team assignment for student scholars enrolled in a cybersecurity scholarship program in our institution. Colorado-Washington Security Scholars Program (CWSSP)[1] offers unique educational opportunities for engineering and computer science students pursuing careers in cybersecurity. It is a cross-campus program between the Department of Computer Science at University of Colorado Colorado Springs (UCCS) and the School of Engineering and Technology at University of Washington Tacoma (UWT) and provides the students in both institutions with financial scholarship and research and job opportunities in cybersecurity. CWSSP is a part of the CyberCorps Scholarship for Service (SFS) program, a network of approximately 50 institutions in the US and funded and overseen by NSF, DHS, and OPM.

CWSSP prioritizes *teamwork* in its program because of its importance in cybersecurity. Cybersecurity requires a systems view and collaborations among people from different domains. For example, security risk assessment and threat analyses (involving domain expertise in application and offensive technologies) can inform the research and development on the defense (involving software, networking, and hardware expertise). It is difficult to achieve security and assurance on a system by focusing solely on a system component or relying on a particular skill domain, because the security is only as strong as the weakest point in the system which may not be addressed without the overall systems view enabled by a diverse set of expertise. All students selected for the scholarship are from the computer science or cybersecurity degree programs hosted in the engineering college in both institutions.

B. Virtual Teams Course in CWSSP

In keeping with the CWSSP program's emphasis on team collaboration skills, all students enrolled in the scholarship program are required to take a course titled ”Virtual Teams”, which is offered fully online during a period of three weeks. While the course work in their degree programs focus on technical concepts related to cybersecurity, the purpose of the Virtual Teams course is for students to enhance their teamwork and collaboration skills in the cybersecurity context.

The course objectives are to help students recognize the impact of team communication on the success of cybersecurity work teams, and develop strategies for structuring individual roles in work teams. The course consists of three modules, each of which included relevant readings, online discussion, and individual or team assignment. The course was offered twice during 2019-2020. In each course, students were randomly assigned to a team of 3-4 members. Fourteen students in total (four females and 10 males; six undergraduates, six Master's, and two Ph.D. students) were included in this case study.

The knowledge sharing assignment we designed was embedded in Module 2, in which students learned about team structuring processes. The module content focused on how to harness knowledge resources individual members bring forth in work teams and how to delegate individual roles according to each member's strengths and expertise.

IV. Description of the Assignment

A. Conceptual Preparation

Before the students were introduced to the team assignment, they engaged in several activities to be conceptually prepared for the assignment. First, students read a scholarly article about how software development teams encounter a variety of barriers to effective knowledge sharing [15], in which TMS theory was introduced as a conceptual tool for team collaboration. Secondly, students viewed the instructor's recorded

[1] https://uccs.edu/cwssp/

lecture on team structuring, in which further elaboration of the TMS theory was embedded. Additionally, the lecture offered examples of what TMS looks like in work teams in a variety of sectors including cybersecurity, business management, product campaign, and health care. Lastly, students participated in a discussion forum where they posted their comments on the relevance of TMS for cybersecurity work teams and how they would develop/implement it to their own team in the course.

B. Assignment Structure

The team assignment asked student teams to situate themselves in a hypothetical scenario where they are serving the local city as a Security Team in developing a cybersecurity system for the city's new metro transportation system. The goals of the assignment were for the students (1) to analyze the task requirements in the hypothetical situation, (2) to recognize and investigate each team member's knowledge resources, and (3) to assign individual roles and tasks in line with each member's expertise. The following information was provided for the team task:

> The City of Colorado Springs and the State of Colorado are planning on building a train-based public transportation system in Colorado Springs. The city already contracted a System Integrator but wants to have a separate Security Team design and develop the cybersecurity measures and incorporate them into their new metro transportation system. With increasing cyber control and threats, the city is determined to make the metro as secure as possible against the potential adversaries in cyberspace. The state is asking you to serve as the Security Team. The following are the tasks that they outlined as needed from the Security Team.
>
> Tasks of the Security Team Include:
>
> - INVESTIGATION: Investigate real-world security attacks on metros and public transportation and the state of the art research and designs in metro security, and identify and evaluate security risks for different threats
> - DESIGN: Select required security objectives and design corresponding security mechanisms
> - ANALYSIS: Analyze the overheads, vulnerability and threats of the proposed security mechanisms
> - IMPLEMENTATION: Implement the security mechanisms in software/programming as well as on hardware
> - TESTING AND EVALUATION: Construct the networking- and computing-testbeds for simulation and testing
> - COORDINATION: Oversee the entire team process, and communicate with external stakeholders (e.g., the System Integrator, state and city officials)

Given this scenario, students were asked to develop their own TMS and individual roles by filling out the team assignment sheet illustrated in Table I. Specifically, they were instructed to share and record each team member's experiences in all areas in as much detail as possible and then assign each member a functional role according to the tasks of this security team outlined above. Ultimately, they were required to demonstrate that each functional role was assigned to a team member who had the most experience and expertise for the role and in turn could best fulfill that role. It was highlighted that the submission of the completed worksheet should be each team's joint product that represents extensive discussion about each other's knowledge resources and the team's collective decision on individual roles.

Additional instructions were offered that if their team is unable to fulfill all of the functional roles for this project given what each team member is knowledgeable about, it is acceptable to leave those roles blank and that it is part of the process of learning what their team is and is not capable of (and possibly having to bring new members to strengthen the team's capacity for the team's task).

V. Assessment and Results

To gauge student's learning outcomes in the team assignment, we drew on the instructor's assessment of the quality of students' work, students' anonymous evaluation of the assignment and the Virtual Teams course, and students' informal feedback offered to the instructor and the CWSSP scholarship program director.

A. Assessment of Team Assignment

All teams successfully completed the team assignment, meeting all the requirements. Aligning each member's knowledge and skill sets with each of the six functional roles required in the team task, all teams clearly demonstrated why each member was best suited to perform a particular role. For example, one member in a team was assigned to the functional area of "Investigation" because that member uniquely possessed extensive experiences and skills in research including the abilities in navigating various databases and library resources. Another member in the same team took the role of "Coordination", because compared with other members in the team, that person had the most extensive experience in leadership and collaboration across multiple stake holders although the previous leadership experience was primarily outside the field of cybersecurity. Also, another member demonstrated programming skills in a variety of programming languages and was evidently the most knowledgeable person to perform the role of "Implementation". Through this assignment, all teams revealed the range and diversity of expertise existing at the team level and clearly articulated how each member would make a unique contribution to the team by fulfilling the roles that were closely connected to their strengths.

While students successfully identified each other's specialty, they also observed similarities between themselves and developed their own strategies on how to capitalize on both differences and similarities. One team designated each person as a lead in a different functional role based on the person's relative expertise but at the same time decided to establish the expectation that anyone in the team can also contribute to that area even if they are not the designated lead. This was a unique strategy they came up with as a way to honor each person's strength as well as avoid pigeon-holing them in a particular area.

Team Member's Name	**Academic** Major/Minor Relevant coursework	**Work Experience** Part- and full-time Internships	**Research Abilities** Knowledge of current literature; Literature search; Research Integration; System analysis	**Software and Hardware Skills** Experience in programming languages, software tools, or hardware (e.g., networking, router or server, embedded platforms)	**Communication Skills** Leadership experience; Teamwork skills; Relationship management	**Other Areas of Expertise**	**Assigned Functional Role**
1.							
2.							
3.							
4.							

TABLE I
TEAM KNOWLEDGE SHARING ASSIGNMENT WORK SHEET (AS PRESENTED TO THE STUDENTS BUT COMPRESSED)

Students' discussion board also revealed that they were highly engaged with the conceptual underpinning of the TMS theory and its relevance to cybersecurity professionals. One student commented, "I see the TMS as being highly useful for any team, especially ones in cybersecurity, since team members often have diverse backgrounds. What I like about the TMS is it makes systematic how important it is to learn about the expertise of the team members as early as possible in the team-building process." In the similar vein, another student echoed the applicability of the concept by saying that "I believe that there are definitely uses for TMS in the field of cybersecurity. Oftentimes while I am at work and need assistance on a task, I know exactly who I can go to, who knows more than me in that department, and can ask them for help. Because cybersecurity ranges across so many topics, it is nearly impossible to be an expert on everything. As a result, TMS can be a very useful tool to reference in order to see who knows what."

The evaluation form the students filled out at the end of the course revealed overwhelmingly positive responses toward the team assignment. One student commented "I loved [this assignment] because we got to actually do the assignment as a team. Incorporating this into all modules would have been super fun." Also, eight students out of 10 who participated in the course evaluation reported that they recognized the value of team efforts in the field of cybersecurity more significantly through this assignment.

B. *Assessment of Overall Team Collaboration Skills*

The analysis of the students' feedback on the assignment and the Virtual Teams course revealed a strong positive impact on students' team collaboration skills. In a Likert scale of 1-5 (1 being "strongly disagree" and 5 being "strongly agree"), the mean scores for the following statements were well above 4.0 or 4.5 for some: "My understanding of team processes improved after completing the team assignment", "I feel more confident about my team work skills after completing the course", and "I recognize the value of team efforts in the field of cybersecurity more significantly after taking this course." These results indicate that the learning activities including the team knowledge sharing assignment made positive impacts on the students' team collaboration skills.

VI. DISCUSSION AND TAKEAWAYS

In this paper, we presented a team knowledge sharing assignment that we used for Virtual Teams course designed for cybersecurity students and reported our experience with the design, facilitation, and the outcome of the assignment. Under the larger umbrella of team-based pedagogy, this team assignment highlights why team collaboration skills, particularly in the area of knowledge sharing, in computer science education are critical in preparing students for future career in the field and offers a tangible and concrete framework for how to facilitate students' learning in team collaboration skills. By drawing on a team communication theory in the design of the assignment for cybersecurity students, this case study makes a unique contribution to cross-disciplinary efforts in computer science education. In the following, we discuss how the assignment could be extended and applied to other instructional settings and offer practical suggestions for other instructors when they adopt and facilitate this assignment.

A. *Extension and Application of the Team Assignment*

1. Apply to other subject areas: We designed the assignment specifically for cybersecurity students, and therefore, contextualized it in a cybersecurity-specific problem solving situation and functional roles and areas of expertise relevant to that situation. However, the underlying principles grounded on the TMS framework would be applicable to any other subject areas. For instance, the assignment and the embedded tasks in Section IV-B can be adapted to a software development project for a system application. For a software development project, the functional roles for *Design* can be described as identifying project objectives to fulfill application requirements, selecting underlying techniques and approaches for implementation, and integrating sub-components to the system application.
2. Extend to long-term class projects: The assignment was implemented in a three week long short course as part of a scholarship program, but we believe that the assignment would offer more benefits to longer-term project teams for an entire semester. In keeping with Team Based Learning model on the effectiveness of working with the same team throughout the term, this assignment can be used as an initial team building exercise in the beginning of team formation in which students learn about each other's background and training. In addition, instructors can take a longitudinal approach to TMS

development in student teams by requiring them to revisit the knowledge directory they created in the beginning of the term at different points in time throughout the semester. This would allow students to recognize how TMS could be modified and evolve over time and how individual roles may need to stay flexible according to the evolution of their TMS.

B. Suggestions for Instructor's Facilitation

Based on our experience in facilitating the team assignment reported in this case study, we offer several practical suggestions on how instructors can create as positive learning experience for students as possible and maximize the potential benefits of the assignment.

1. Develop concrete functional roles along with examples: We learned that the functional roles we created for the hypothetical scenario served as a critical anchor that students used when determining which backgrounds, previous experiences, or skill sets they share with their team members. This means that the extent to which students share their backgrounds and expertise specifically relevant to the team task at hand hinges on which functional roles instructors require them to fill in for the assignment. Therefore, we suggest that instructors develop functional roles that are critical for the team task and explain what each functional role entails. We found that providing examples for these aspects of the functional roles helped students envision what performing each role would look like.

2. Allow room for flexibility: As students learn about each other's areas of expertise for the assignment, they may find that their team has multiple members who are strong in one area while they do not have any member who has relevant experience in another area. It is important for instructors to communicate to students that these situations are perfectly normal and that it is helpful for work teams to be aware of their team's strengths and weaknesses. What is critical after identifying their areas of strength and weakness is how they capitalize on their strengths as well as figure out ways to address their areas of weakness. We suggest that instructors offer additional guidance to each team on how to fill in the roles the team does not have existing knowledge resources for (e.g., considering swapping members between teams, identifying a member who is interested in learning about a new area).

3. Emphasize the utility of the knowledge sharing process beyond the class assignment: We recommend that when the assignment is completed, instructors devote some time to highlighting how the knowledge sharing processes enacted in this assignment can be used as a practical tool for enhancing team collaboration in other academic and professional contexts. For instance, students can be encouraged to take the initiative in cultivating knowledge sharing in other work teams by incorporating a process like this assignment that purposefully utilizes each member's strengths when assigning individual roles.

VII. Conclusion

This paper showcases a specific team assignment that helps students learn team collaboration skills by identifying and leveraging each team member's knowledge resources and acquiring a hands-on tool for how to delegate responsibilities in project teams. The assignment offers a concrete structure for team knowledge sharing and role configurations that has a range of application potential to fit diverse student projects. Our case study illustrates an innovative cross-disciplinary effort by applying a communication theory to computer science and cybersecurity education, and we call for more interdisciplinary initiatives in engineering education research.

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