Characterizing Team Cognition Within Software Engineering Teams in an Undergraduate Course

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***Abstract*—*Contribution:* The study characterizes aspects of cognitive and metacognitive dimensions of team cognition of software development teams in educational settings.**

***Background:* The software development industry requires software engineers and developers to work in teams; for this, there is substantial research on teamwork in the context of the organization. However, little is known about it in the context of educational settings, where there is scant research on teamwork in engineering and computing projects.**

***Research Questions:* How do students enact teamwork cognitive engagement and metacognitive regulation in the context of a systems analysis and design course?**

***Methodology:* The participants were 127 undergraduate students in a systems development course organized into 26 teams. Qualitative categories were derived from a content analysis based on recorded teamwork sessions, which were then quantized and visualized for pattern identification.**

***Findings:* Results provide each team's overall cognitive engagement coefficient and metacognitive regulation coefficient. The findings also describe three clusters, each with a description of a selected team to provide further insights into the identified patterns.**

***Index Terms*—Cognitive engagement, metacognitive regulation, software development, team cognition, teamwork, undergraduate education.**

I. Introduction

THE INTERDISCIPLINARY nature of 21st-century workplaces requires science, technology, engineering, and mathematics (STEMs) graduates to possess a blend of technical and professional skills, including communication, teamwork, leadership, and problem-solving [1], [2]. Among these critical skills, teamwork has become essential to organizations [3] because of its main contribution to organizations' goal achievement. Consequently, organizations and governments expect higher-education institutions to prepare students to engage at employment outset as productive members and leaders of teams [4]. As a response to the need for effective teamwork skills, STEM educators have integrated teamwork into their teaching practice [e.g., [5]]. Although there is substantial work on identifying conceptual models, taxonomies, and empirical studies demonstrating the importance of teamwork to effective team performance in the organization, little is known about it in the context of educational settings [6]. For example, a systematic review of the literature identified that there is scant research on teamwork in engineering and computing projects [7]. However, literature on teamwork from organizational psychology and organizational behavior perspective reported findings on team effectiveness in the organization over the past ten years [8]. The researchers identified three primary dimensions in which teamwork has been studied: 1) compositional features, such as team members' demographic backgrounds, individual abilities, and personality; 2) structural features, such as task scope, interdependence of tasks, and complexity; and 3) mediating mechanisms, such as motivation, trust, and cohesion, among others [8]. However, this same study called for research that focuses on aspects of team dynamics that go beyond static depictions of team processes and outcomes and focusing more on *interactions* initiated by individual team members and the impact on other team members at a particular point in time [9].

The present study aims to contribute to the understanding of team interactions by characterizing team cognition in the context of a software development systems analysis and design course. Team cognition refers to the emergent state where knowledge essential to team functioning is mentally organized, represented, and distributed, allowing team members to anticipate and execute actions [10]. Specifically, this study will characterize aspects of cognitive and metacognitive dimensions of team cognition. The specific research question is: *How do students enact teamwork cognitive engagement and metacognitive regulation in the context of a systems analysis and design course?*

II. Background

A critical outcome of teamwork is team effectiveness, which has been the focus of multiple studies. Team effectiveness has been characterized in terms of 1) tangible outcomes

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in terms of productivity, efficiency, and quality and 2) the influences on team members, such as shared experiences, cohesion, and psychological safety [8]. Integrative studies have applied the input-process-outcome (IPO) model [11], focusing on the team's inputs, team processes that transform inputs into outcomes, and team outcomes [12]. Team inputs include contextual factors, such as organizational design, team-level factors, such as task structure, and team member characteristics, such as personality. Team processes include task-focused interactions like coordination, communication, and cooperation. Team outcomes include team performance and team member affect [13]. Other approaches include investigating the evolution from groups to teams by focusing on developmental stages [e.g., 14], transitioning from dependence and inclusion to trust and structure, to work and productivity [15]. Studies have also focused on mediating mechanisms, such as communication, cohesion, coordination, and relationship building [16]. As observed from previous approaches, multiple perspectives have been taken to study teamwork in organizations along with the factors necessary for such teams to be effective. In recent meta-analytic work, these factors have been summarized as 1) compositional features, focusing on team members' characteristics; 2) structural features, focusing on the characteristics of the work to be completed; and 3) mediating mechanisms, focusing on behaviors and attitudes [8]. However, research that considers the dynamic and contextual features of teamwork, based on observational studies and action research, is highly needed in order to understand better-team interactions and how those can be positively influenced by interventions [8], [17]. For this, a research perspective is needed where teamwork is studied at the team level, as an activity, and tied to the specific context [18].

For the purpose of the present study, an interactive team cognition (ITC) perspective was adopted, which argues that team cognition resides in team interactions and the activities they perform during teamwork sessions [19], [20]. Team cognition is an important contributor factor to team performance [3], [21].

A. Teamwork Research in the Context of Software Development

The software development industry requires software engineers and developers to work in teams [22], especially in the context of an agile environment [23]. Traditional software development follows a hierarchical approach where often the team manager plays a crucial role in driving the team's goals and objectives [24]. Gradually, the focus of software development companies has started to adopt user-centered approaches, and that has led to some structural shifts in software development teams. Such teams have become more flexible in accommodating customer requests, forming agile teams [22]. Agile teams are self-managed teams where each team member is responsible for their tasks, and together, as a team, they are responsible for the team's overall success [25]. Since agile is an iterative customer-centric approach to creating software products, it requires team members to possess a variety of skills for meeting consumer needs on time [26]. Timely delivery of products is not possible without a strong team commitment [27]. Thus, software development teams need to ensure that they continuously communicate, collaborate with others to deliver the product, and meet customer needs.

Research has identified the complex nature, tasks, resources, and people involved in software development [28], [29]. For instance, Dingsøyr et al. [30] identified five factors that influence teamwork performance in the software development team, including 1) team coordination establishing collaboration among the subteams; 2) goal orientation helping to set a jointly agreed target for the team; 3) team cohesion promoting team commitment and reduces the chances of conflict among the team members; 4) shared mental models allowing the team members to share their repertoire of knowledge and learn from one another; and 5) team learning as the result of shared mental models helping the team members to develop team skills. In addition, recent research focused on how teams apply knowledge in the context of software development teams identified the critical role of the evolving nature of the artifacts the members produced throughout the software development cycle [31]. For instance, abstract and system thinking processes are needed in order to define software systems in terms of functions, structures, and behaviors [32]. Thus, teamwork performance in the context of software development is greatly affected by shared understandings, as well as coordination processes.

B. Teamwork Within Educational Settings

A systematic literature review on teamwork in educational contexts has identified that research in the context of higher education has mainly focused on describing instructional strategies used to teach teamwork knowledge, skills, and abilities [17]. Some of these instructional strategies include teaching collaborative and cooperative teamwork [17] and introducing team training tools for students [33]. This research has also heavily focused on assessments [17]. Studies indicate that grading teamwork efforts is one of the major issues faced in higher-education contexts [17]. For instance, most higher-education students report social loafing as a concern with assessments. Research findings suggest that collaborative peer assessment methods are preferred by most students in solving assessment issues [17].

Meta-analytic research on teamwork within organizations has identified that team training interventions are viable for enhancing teamwork performance [34], [35]. McEwan and colleagues [35] identified positive and significant medium-to-large-sized effects for interventions on teamwork and large effects on team performance. Their meta-analysis also identified that teamwork interventions were effective for both new and existing teams, regardless of the types of interventions. Didactic lectures, workshops, simulation training, and review-type activities were equally effective [35]. Previous work's implications suggest that teamwork capability can be improved through effective teamwork pedagogy [17]. However, a relatively recent systematic review concluded that teamwork

research in higher education is understudied, calling for the need to better inform research in education from research within organizations [7]. The study aims to contribute to the teamwork literature in higher education and will utilize the lens of team cognition to investigate students' teamwork interactions in the context of a semester-long software development project.

III. Theoretical Framework

Team cognition is needed in order to improve team performance [6]. Team cognition refers to a property or a characteristic of a team that describes how the knowledge is organized, represented, and distributed among team members, which also enables team members to anticipate and coordinate [21]. One perspective of team cognition, ITC Theory [18], argues that team cognition resides in team interactions—i.e., activity and interactions [19], [20]. Team interactions involve team members' application of knowledge as shared cognition. Thus, team cognition involves characterizing how knowledge is distributed among team members and how team members tap on that knowledge to perform a task [20].

From the perspective of shared cognition, a team's knowledge overlaps among all the individuals, resulting in shared mental models, where team members share an elevated level of knowledge about a task [20]. As each member has a different piece of knowledge and possesses different abilities, interaction in the form of communication allows individuals to obtain information from one another, which leads to the completion of the task [20].

Interactions also involve behavioral processes consisting of members' interdependent actions that translate efforts to outcomes via cognitive, verbal, and behavioral activities for organizing tasks toward achieving collective goals [36]. These involve activities, such as planning, coordinating, decision-making, assessing situations, and solving problems [37].

Researchers focused on investigating team cognition have identified that studies mainly focus on one aspect of team cognition at a time, pointing to a need for studies that interrelate the various aspects of team cognition or capture its complexities [3]. Specifically, more research is needed that describes teamwork cognitive processes, such as how team members efficiently retrieve and utilize expertise, and metacognitive processes, such as how team members manage and coordinate actions [3]. Thus, the implications of the theoretical framework are that the present study focuses on characterizing how students enacted teamwork cognitive engagement processes and metacognitive regulation processes. Specifically, two aspects of team cognition were investigated 1) the application of knowledge and the engagement with the task herein called cognitive engagement and 2) the application of communication and coordination processes herein called metacognitive regulation.

A. Teamwork Cognitive Engagement

Teamwork cognitive engagement focuses on processes involving team members' engagement with solving the task by applying knowledge and expertise. The study used the interactive-constructive-active-passive (ICAP) framework to characterize teamwork cognitive engagement [38]. The ICAP framework has been used in classroom settings to describe four different models of cognitive engagement in active learning. The ICAP framework has also been used as a lens to study teamwork interactions and group behavior [e.g., [39] and [40]]. This model proposes four categories of engagement according to overt behaviors in the learning process [38]. According to Chi and Wylie [38], each mode predicts a different level of "activeness" in which a student is engaged in a learning task. The highest level is achieved in the interactive category [38], in which students constructively interact with other team members, meaning they are constructing ideas related to the team's task. This interaction must be significant, so there needs to be enough turn-taking in the conversation between the students [38]. The behavior displayed when a student is being interactive is co-generative collaborative behavior [41]. The next level is attained in the constructive category; constructive behaviors are those in which students individually produce ideas or generate outcomes related to the task [41]. The level of active is characterized by students engaging with the learning material actively but not constructively [38], which means they are in some way interacting with the material or showing signs of active engagement but without producing ideas. The last level is related to the passive category involving behaviors where the student mostly receives information from the material or task, not engaging with it [38].

B. Teamwork Metacognitive Regulation

Teamwork metacognitive regulation involves team members' communication and coordination processes. Dickinson and McIntyre [42] proposed a model that characterizes the seven core components of teamwork, including communication, team orientation, team leadership, monitoring, feedback, backup, and coordination. This model has been extensively used to characterize team behaviors that may lead to team performance [e.g., [43], [44], and [45]]. Specifically, communication and coordination processes include behaviors associated with team orientation, team leadership, communication, monitoring, feedback, backup, and coordination processes [42]. Team orientation includes the attitudes a team member has toward the team and other team members. Team leadership refers to the structure and direction a leading team member can give to the group. Communication is the exchange of information between team members. Monitoring refers to the observation and awareness of the tasks and performance of other team members. Feedback relates to giving or seeking feedback from other team members. Backup involves helping other team members perform a task. Coordination refers to the way team members respond to the behavior of others executing the team activities [42]. These seven components will guide the characterization of teamwork metacognitive regulation behaviors.

IV. Methods

The present study implemented a content analysis approach [46]. Content analysis has historically been used

since the 18th century in Europe and the United States both as a qualitative and a quantitative method [46]. Since the 90 s, content analysis has been used as an approach to coding text data into explicit categories and then describing those quantitatively using statistics or other visualization methods [47]. In this study, content analysis was used as an approach where qualitative categories were quantified and visualized to inform the identification of groups and patterns within the groups regarding teams' enactments of cognitive engagement and metacognitive regulation. Content analysis was deemed as an adequate approach because the goal was first to understand the contextual circumstances of the observed behaviors and then interpret such behaviors in the context of teamwork.

A. Context

The context of this study was a second-year systems analysis and design course offered every spring and fall semesters at a midwestern university in the USA. This course was selected because it is a required course for all undergraduate students pursuing software engineering, cybersecurity, and network engineering majors. The course aims for students to apply object-oriented software development methods for identifying and modeling requirements and translate those models into a system solution in the form of a functional prototype. Two specific methodologies were concurrently taught. The Unified Process [48] and the Unified Modeling Language [49] were used to identify, document, and model requirements culminating in a systems requirement specification. Scrum practices [50] were also implemented to guide students into enacting specific *roles*, including scrum master or member of the development team, generating specific *artifacts,* including product and sprint backlogs and the actual prototype, and engaging in specific *events*, such as sprint planning, five iterative sprint increments delivered every one or two weeks throughout the semester, along with team retrospectives.

The course involved a semester-long project organized into three milestones (i.e., the system requirements specification) and one final project prototype delivered into four sprints (i.e., the functional prototype).

B. Participants

Participants for the study included 118 students who were enrolled in the systems analysis and design course offered in the Fall of 2021 when the course offering resumed a fully in-person class format after the COVID-19 pandemic. The students were organized into 26 teams, each team with at most four students. According to institutional data, there were 29 female and 89 male students. Fifty-seven students reported their race as White, 13 as Asian, ten as two or more races, six as Black or African American, and two as unknown. Three reported their ethnicity as Hispanic or Latino. The remaining 27 students reported themselves as International with no indication of race or ethnicity. Students' ages ranged from 18 to 26 years old, with an average of 20 years of age. Previous required preparation for this course included a first-year course focused on leadership, teamwork, and globalization and an introductory first-year course in systems analysis and design. As part of these courses, students 1) developed solutions applying the principles of human-centered design; 2) worked in teams; and 3) applied structured systems development techniques for the design, construction, and testing of an information system. Thus, the students had some foundational knowledge and experience in working with teams and with structured software development methods.

C. Procedures and Data Collection Methods

The in-class orchestration was divided into a Tuesday in-person class and a Thursday in-person or online class. During the Tuesday class, the course instructor introduced software development principles and practices, and the students had an opportunity to practice those individually and as a team. Thursday's class was devoted to teamwork working sessions. A total of four teamwork sessions were scheduled online on a Thursday. To facilitate the teamwork interaction, the instructor used Microsoft Teams. Each team was assigned a private collaborative space, a team channel, on the platform. The functionality of a team channel included private text, audio and video conversations, and file sharing within a single team. Students used the platform to share files and resources in and outside class. Four mandatory online sessions were scheduled throughout the semester. These mandatory sessions were scheduled during class time on Thursday, right before a major deadline. During the second online teamwork session, which was recorded for analysis, students worked on preparing the submission of the first project milestone. The second online session was selected for analysis because it was the first instance in which team members talked extensively, and their lengthy conversations would give researchers a chance to observe their engagement and teamwork processes. All 26 teams were requested to initiate a virtual meeting within their corresponding channel, keep their device cameras on during virtual meetings, and video-record their discussion sessions. Of the 26 recordings submitted, three recordings were excluded from analyses due to bad video and audio quality, and three more were removed because of teams missing one recording. In total, 20 teams were analyzed for this study, each with a duration of an average of 50 min.

D. Qualitative Data Coding Methods

The qualitative content analysis procedures started by observing and codifying students' teamwork interactions enacted during the recorded sessions. Each team recording was analyzed one by one, and for each team, individual student behavior was analyzed. In analyzing the recorded videos, students' names were omitted to keep their information confidential. Students were, instead, identified by numbers. Tables were created in Microsoft Excel to record observations of each team member's behaviors. Individual students' behaviors were analyzed every 2-min interval.

Although coding schemes for team interactions have been developed by organizational psychologists [e.g., [51]], for the present study, it was determined to utilize coding schemes that have been previously used to characterize teamwork behavior in education research. Thus, Chi and Wylie's ICAP framework

was used to characterize cognitive engagement [e.g., [39]], and Dickinson and McIntyre's model was used to characterize metacognitive regulation [e.g., [24]].

By observing and codifying students' behaviors, an initial coding scheme was developed where aspects of cognitive engagement and metacognitive regulation were characterized. As described in Section III, the students' levels of cognitive engagement were codified into interactive, constructive, active, and passive, according to Chi and Wylie's ICAP framework. The students' forms of metacognitive regulation were codified as team communication, team orientation, team leadership, monitoring, feedback, backup behavior, and coordination, according to Dickinson and McIntyre model. For each of the codified behaviors, specific descriptions were generated based on students' enactments, as shown in Appendixes A and B, respectively. For example, one description for an overt cognitive behavior categorized as Passive was "A group member shows signs (such as nodding) of listening to other group members without uttering a word or taking notes." One description for an overt behavior categorized as Active was "A team member reading out instructions indicated in the assigned project and asking clarification questions."

In identifying and characterizing the forms of cognitive engagement, it was also observed overt behaviors that were not indicative of students' engagement. As a result, two additional codes were developed. It was defined as *cognitive disengagement* to all activities or behaviors unrelated to the learning activity at hand. Examples of descriptions of cognitive disengagement behaviors to match the learning activity at hand were actions, such as leaving the meeting, being absent (chatting, speaking with other people, and looking at their phone), or being present during the meeting but having their cameras off. The display of cognitive disengagement behaviors also indicated team members not paying attention or working on tasks other than what was specified. It was defined *disruptive behaviors* as actions that slow down group progress or the attainment of group goals. The display of disruptive behaviors also affected group morale and performance. Examples of descriptions of disruptive behaviors were yelling at other team members, arriving late to group discussions, or ignoring other group members. These codes are also included in Appendix A.

As shown in Appendix B, specific overt behaviors for metacognitive regulation were identified using the theoretical definitions of team communication, team orientation, team leadership, monitoring, feedback, backup behavior, and coordination. For example, one description for an overt behavior categorized as Team Leadership was "A group member deciding on roles and tasks team members should assume and complete, respectively." All descriptions of overt behaviors categorized as codes describing cognitive engagement and metacognitive regulation were collated into a document to create a codebook (i.e., coding scheme).

In coding the data, certain rules were followed. The raters were to avoid double-coding items related to cognitive engagement, cognitive disengagement, and disruptive behavior. This means that team members' behaviors could not be coded in more than one category. This is because the raters determined that behaviors were going to be coded based on the highest level of engagement category. On the other hand, double coding was allowed for the seven components describing team members' metacognitive regulation behaviors. This means that team members' behaviors could be coded under more than one category. Double coding was allowed for the seven components because team members could exhibit more than one teamwork process in the 2-min interval, and such information had to be captured to explain the metacognitive regulation of members in its entirety.

E. Trustworthiness Considerations

Three raters, all with expertise in qualitative research, coded 20% of the data together, after which the 80% left was coded single-handedly by two raters. Before independently coding the data, the three raters went through three cycles of analysis to ensure inter-rater reliability was strong for the first 20% of the data. In the first cycle, all raters analyzed some videos individually, after which they came together to discuss similarities, differences, and areas of improvement for coded data. In the second cycle, raters coded the data together to ensure everyone agreed with the comprehension of the coding process. In the third cycle, the raters coded the data individually again and arrived at an inter-rater reliability score of 88%.

F. Quantizing Qualitative Data

An approach to complement content analysis involves transforming codes into quantitative data [46], [47], [52]. This transformation further allows for 1) the exploration of qualitative data to identify patterns and 2) the reporting of trends within larger sample sizes by visualizing such trends [52]. In the study, the qualitative codes were quantized in order to uncover patterns in students' behaviors. For this, each team was assigned a cognitive engagement and a metacognitive regulation score.

First, individual scores were assigned to each team member for each of the observed behaviors, and based on those, an overall score of cognitive engagement and metacognitive regulation was generated for each team. For calculating the team cognitive engagement coefficient, weights were assigned to each construct, representing the level of engagement of each team member. Specifically, the assignment of weights followed the level of engagement, so interactive was assigned the highest weight (2), followed by constructive (1.5), active (1), and passive (0.5). Cognitively disengaged and disruptive behaviors demonstrated no engagement; therefore, they were given a score of negative one (-1).

Further, to calculate the team cognitive engagement coefficient, the frequency of each behavior demonstrated by a particular student was multiplied by a weight and divided by the total number of time slots (1 time slot is equal to 2 min). Then, the overall average value for the team was calculated. The calculated average value was the team cognitive engagement coefficient for the team. The calculated average value for the team cognitive engagement coefficient ranged from -1 to $+2$. Table I represents the criteria used to interpret the overall team cognitive engagement coefficient.

TABLE I
INTERPRETATION OF COGNITIVE ENGAGEMENT SCORES

Overall Cognitive Engagement Mean Score	Interpretation
-1 to 0	Poor
0.1 – 0.5	Fair
0.51 – 0.99	Good
1.00-2.00	Excellent

TABLE II
INTERPRETATION OF METACOGNITIVE ENGAGEMENT SCORES

Overall Metacognitive Regulation Mean Score	Interpretation
0.00-0.33	Low
0.34 – 0.67	Moderate
0.68 -1.00	High

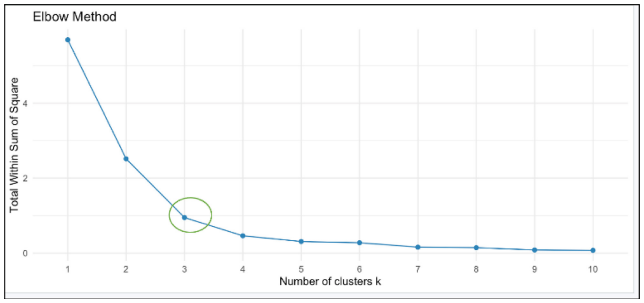

Fig. 1. Visualization of the results from the application of the elbow method indicating three clusters.

Similarly, the team metacognitive regulation coefficient was calculated based on each of the coded behaviors. Since the Dickinson and McIntyre model does not follow a hierarchy of more desirable behaviors, all the codes were assigned a weight of a positive one, except for team orientation, which was considered either negative or positive. (Recall that disruptive behavior was part of the cognitive engagement and was assigned a negative one). The frequency of each student was divided by the total number of time slots, and the overall average value for the team was calculated. The calculated average value is the team regulation coefficient. For the purpose of analysis, the scores were normalized on a scale of 0 to 1. Table II presents the criteria for interpreting the overall team regulation score.

G. Clustering Analysis and Visualization

The team cognitive engagement and team metacognitive regulation coefficients served as input for the clustering algorithm. Specifically, Ward hierarchical clustering was used to conduct the clustering since the study was exploratory and the sample size was small [53]. Before the clustering, the optimum cluster number for the given data was identified using the Silhouette and Elbow method [54]. Both methods determined three as the optimum cluster of the given data, as shown in Fig. 1. A representative team from each of the three clusters was selected to elaborate further on the findings. For each of the three teams in each cluster, visualizations of behaviors in the form of heatmaps were further created to assist with interpreting and describing the overall patterns. The teamwork behaviors in terms of cognitive engagement and metacognitive regulation were presented as narratives over time.

V. RESULTS

The findings first present the overall cognitive engagement coefficient per each behavior and each team and the overall metacognitive regulation coefficient per each behavior and each team. Then, findings present and describe each of the clusters identified, along with a description of a selected team, to provide further insights into the identified patterns.

A. Overall Team Cognitive Engagement

The team cognitive engagement coefficient for each identified behavior and for each team ranged between –1 to 2, as shown in Fig. 2. From Fig. 2, it can also be identified that the dominant engagement behavior demonstrated by most student teams was active engagement, meaning students actively participated while working on the group project during the online session. Specifically, active participation involved students discussing and taking notes while working on the assignment; some were silently working through the problem and only talked when they had a question or wanted to share input. Instances were found where students repeated and reflected on the suggestions of other team members and asked questions for clarification. The second most observed engagement behavior was passive engagement, meaning that some students in the team were observing quietly rather than verbally communicating their thoughts. In this case, it was observed that some team members actively listened to team members, as nonverbal communication patterns, such as nodding heads in agreement were noted. The third most demonstrated behavior was cognitive disengagement, as demonstrated by most teams. This involved some students in teams paying less attention to the learning as they looked through their phones or listened to music while team members were discussing the problem. It was also noted that some team members were absent-minded while others were having a productive discussion. Students also demonstrated other engagement behaviors, such as interaction, knowledge construction, and disruptive behavior, but those behaviors were not dominant.

B. Overall Team Metacognitive Regulation

The heatmap in Fig. 3 represents the metacognitive regulation behavior of all the teams. From Fig. 3, it can be observed that all the teams showed a high degree of teamwork orientation and communication skills. This involved team members showing an ability to understand the attitudes and behaviors of the other team members. Also, they showed skills to actively engage in communication with their team members. It was also noted that student teams demonstrated low to high-feedback-providing and seeking attitudes, such as reaching out for help, providing inputs, or receiving feedback on a task, with 65% of students having shown a moderate to high score. A low degree of metacognitive regulation was observed in terms of coordination, where only one team showed a moderate level of ability to coordinate and lead. All other teams showed a low degree of coordination, evidenced by team members focusing less on planning the assigned task and paying less attention to scheduling their next meet-up times to work on the project. Similarly, student teams showed almost

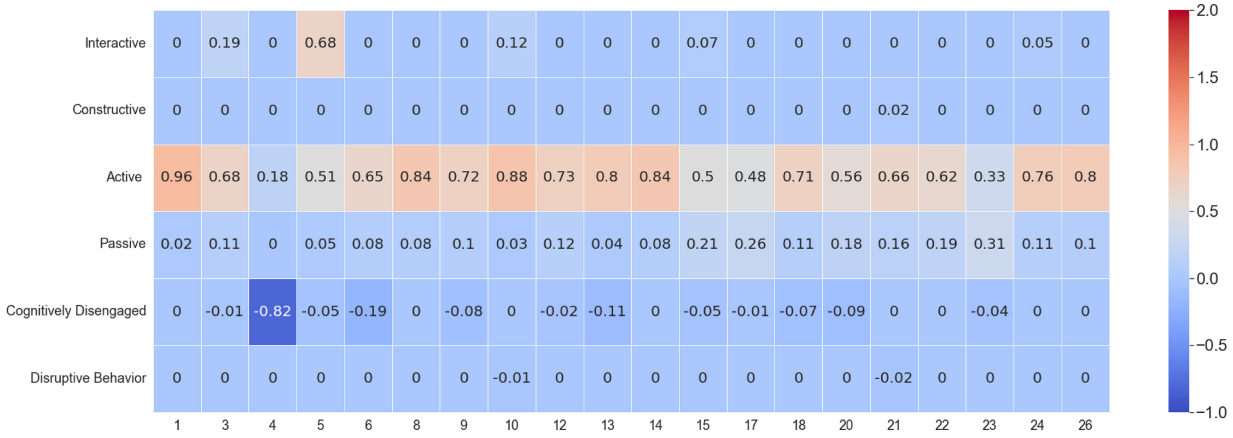

Fig. 2. Team cognitive engagement coefficients per each identified behavior and team.

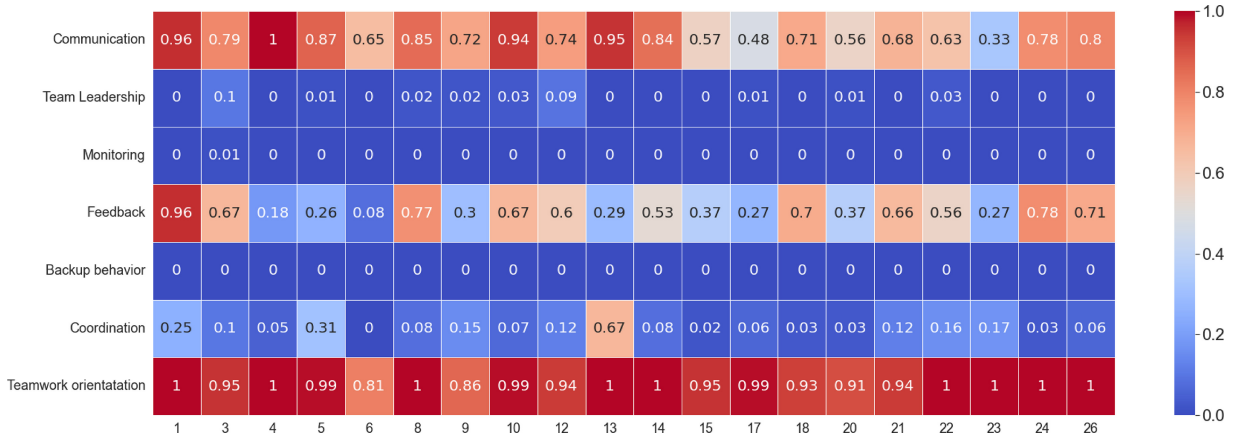

Fig. 3. Team metacognitive regulation coefficients per each identified behavior and team.

a negligible degree of monitoring skills, and backup behavior was completely absent for all the teams. Negligible degree of monitoring skills signifies that student teams did not refer back to the task completed by other team members, and there was an absence of backup behavior, which means that student teams lacked the skills to fill in for other team members or help them to correct their mistakes.

C. Cluster Analysis Results

The results derived from the cluster analysis identified three clusters. Cluster 1 consisted of 13 teams that demonstrated high-team regulation and a good to excellent level of team engagement. Cluster 2 consisted of six teams that demonstrated a moderate level of team regulation and a good level of team engagement. Cluster 3 consisted of one team with a moderate level of team regulation and poor team engagement.

Cluster 1 (High Engagement and High Regulation): The teams in Cluster 1 are characterized by high-engagement and high-regulation scores. This means students in these teams were engaged in the task and the teamwork and had good regulation processes within the team. The students of the teams included in this Cluster were working together on the task; during the team session, they would share their screens to complete the task together or coordinate how they would compete. This high engagement, effective communication, and positive orientation led to the high scores obtained. Teams in Cluster 1 are Team 1, Team 3, Team 5, Team 8, Team 10, Team 12, Team 13, Team 14, Team 18, Team 21, Team 22, Team 24, and Team 26.

To provide deeper insights into the cognitive and metacognitive enactments of teams in Cluster 1, Team 5 was selected as a representative case. Team 5 consisted of four male students. The team was very focused and preplanned the work they would like to cover during the meeting. One of the team members had created a baseline for the context diagram and kept it on Google Drive for team members to collaborate. One student took the lead and started reading the case. Other students read the case silently and started sharing their thoughts. S1 student shared his screen and copied the baseline diagram on draw.io software. S2 was sharing his inputs on the diagram; in the meantime, S3 and S4 looked through the case to ensure that the team was on the right path. S3 raised a question regarding an entity in the case “What should we do with the caterer in the case?” S3 and S4 shared their opinion, and as a team, they decided to omit the entity from the context diagram and assumed that “each venue has its own caterer (therefore, no need of this entity).” The team also demonstrated an effective division of work as S1 and S2 were

responsible for creating the context diagram, whereas S3 and S4 provided feedback and looked through the case to identify if they covered everything required. The team continuously took and provided feedback to one another. For example, while working on the context diagram, S4 asked, "Should we put the stuff like contact numbers and addresses in the context diagram or not?" S2 responded, "I do not think so, as they are more of attributes, and in this diagram, we are focusing on entities, and entities are actors, and we are looking at how they are interacting."

The feedback, in this case, helped the team members to understand the difference between attribute and entity in the context diagram. The team demonstrated constant communication and positive team orientation for the whole team. They were deeply engaged with the content. S3 and S1 did demonstrate some cognitive disengagement; for S3, the Internet connection was not stable; therefore, he had to disconnect a couple of times, which made him cognitively disengaged at that moment. For S1, there were a few moments where he was momentarily looking into his mobile phone and cognitively disengaged. Positive observations included the team having a participative approach; therefore, it was hard to identify a leader. During the session, the team completed the specific tasks they planned to achieve. Before the end of the meeting, students divided the report writing among themselves and decided on their following meeting times. Overall, as a team, they were communicative and active; each team member took the initiative and demonstrated ownership of their task. They demonstrated both excellent team engagement and high-team regulation.

Fig. 4 represents the heatmap for cognitive engagement (top) and metacognitive regulation (bottom). The heat map demonstrates the activity of each student in terms of engagement and regulation for the total period. From the heat maps, it can be inferred that all students demonstrated a high level of interaction and were actively engaged while working on the assignment. Students were constantly communicating their thoughts and ideas, coordinating the work, and providing feedback; overall, a positive team orientation was seen.

Cluster 2 (Medium Engagement and Medium Regulation): The teams in Cluster 2 were characterized by having a medium level of cognitive engagement and a medium level of metacognitive regulation. This means that students in these teams were engaged in the task but were mainly active or passive, or there were distractions in some sessions. This finding suggests that the teams in this Cluster generally worked individually while still attending the teamwork session, so they would only speak to ask for help or to coordinate the team's work. Teams in Cluster 2 included Team 6, Team 9, Team 15, Team 17, Team 20, and Team 23.

To provide deeper insights into the cognitive and metacognitive enactments of teams in Cluster 2, Team 15 was selected as a representative case. Team 15 represents Cluster 2, where students demonstrated moderate engagement and regulation. Team 15 consisted of four male students who met for 15 min. At the start of the meeting, all four students were actively discussing the project. S2 had left the meeting for some reason,

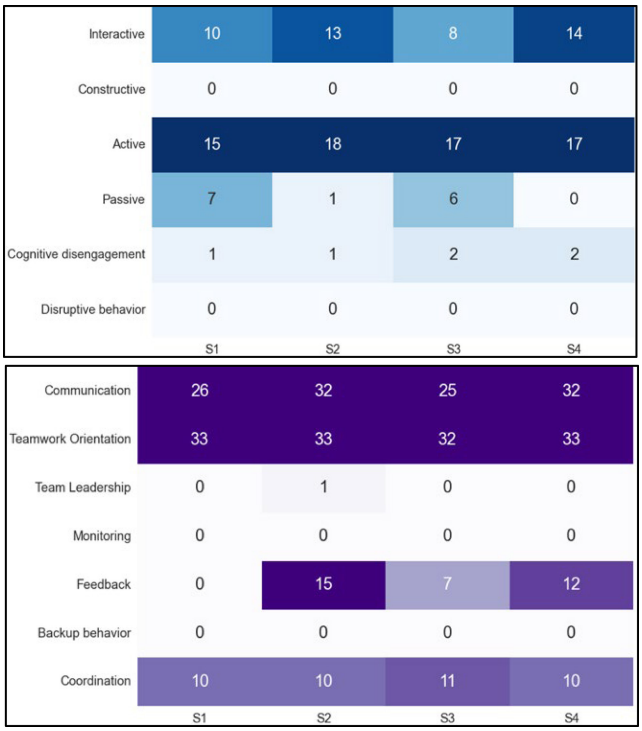

Fig. 4. Heatmap visualization for Team 5 behaviors regarding cognitive engagement (top) and metacognitive regulation (bottom).

and the other three students silently worked on the project. S1 had a question related to the context diagram, and S3 and S4 provided feedback. In the meantime, S2 reached out to S1 as his computer was not working, and he was marked cognitively disengaged for that duration. S2 was a passive listener most of the time as he sat and observed the other three students working. S1, S3, and S4 were actively working on the assigned task; it was noteworthy that the team had distributed the task among themselves before the meeting and were actively engaged in completing their assigned task. Students S1, S3, and S4 kept asking questions to seek feedback from the team. For example, S1, while working on the project, asked about the next steps, and S2 immediately responded on the required task to complete "that we have a backlog to do and then the retrospectives." S4 was unclear about the project deliverables and asked questions about the product backlog and retrospectives; S1 explained to S4 about the product backlog and retrospectives, and S3 silently worked on his assigned task.

All the team members demonstrated a positive orientation and a sense of responsibility. The team members were accommodating to S4 as his computer was not working. At the end of the meeting, all four students divided the tasks they needed to complete as a team. S1 summarized the tasks and responsibilities. The overall team demonstrated good teamwork and engagement throughout their meeting time.

Fig. 5 shows that team 15 was active most of the time and interactive for once. S3 was more passive than active most of the time; the reason for this could be that the team had already divided their task before the meeting, so S3 was more focused on completing the assigned task. It can be observed moderate communication and positive team orientation throughout the

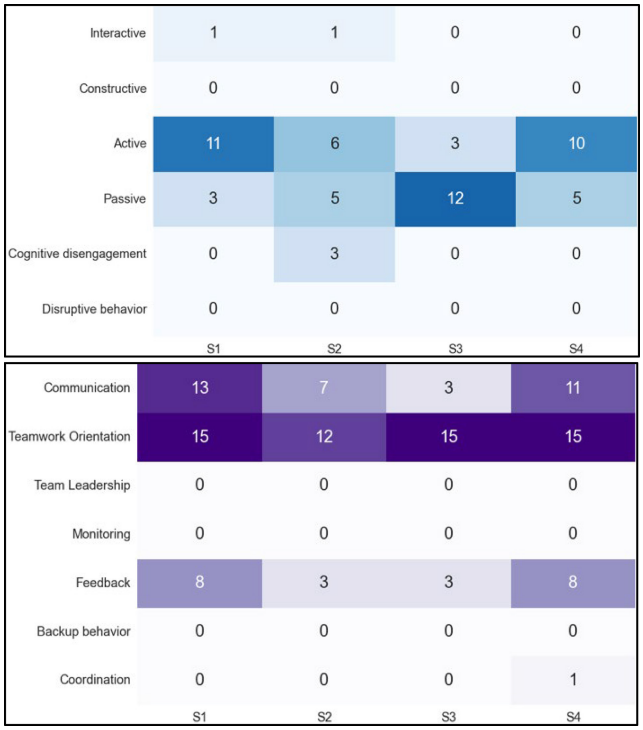

Fig. 5. Heatmap visualization for Team 15 behaviors regarding cognitive engagement (top) and metacognitive regulation (bottom).

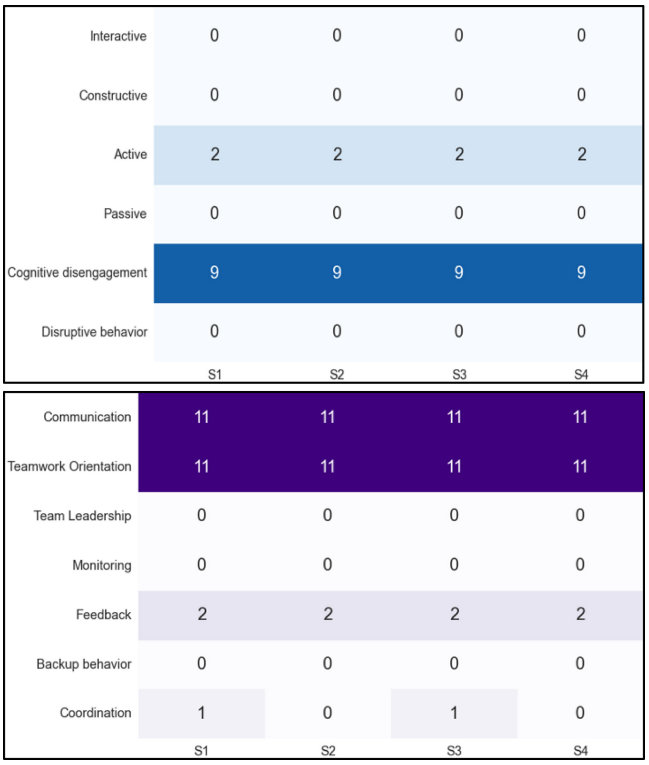

Fig. 6. Heatmap visualization for Team 4 behaviors regarding cognitive engagement (top) and metacognitive regulation (bottom).

meeting session. Students did ask for and provide feedback to one another.

Cluster 3 (Lower Engagement and High Regulation): Cluster 3 contained one team, Team 4, which had a low-engagement score (negative) and a moderate regulation score. This means that students in this team were not engaged in the task but had good team regulation processes. The students in this team were socializing during most of the recording, so they were not talking about the task or engaging with it, but they had excellent communication and positive team orientation; thus, the team got a negative engagement score but a good regulation score.

Team 4 consisted of four students, three male and one female. This team met for about 20 min duration. At the start of the meeting, team members did not say anything for the first 3 min of the meeting. Then S3 tried to break the silence, and he began with an informal discussion "[student name] I like the flag in your background." S2 said "thanks" and asked a question related to the project "Any examples of the cashflow diagram? We do not need that, right?" All the other three students start discussing whether the cash flow diagram is required or not, and then again, they go into silent mode for a minute. This time, S2 starts an information conversation "How do you guys start your morning?" S4 mentioned, "lying in bed like an hour and trying to get up." S3 said, "snooze for around 30 min." S1 mentioned, "I do not sleep; if I sleep, I go for a run." The team member continues to talk about their habits, choices, etc., demonstrating an excellent example of team bonding. The discussion around the project was very limited in the 20 min meeting, where the team was just twice actively engaged. However, they were good at communicating and collaborating and demonstrated positive team orientation. The overall team demonstrated an excellent example of a team bonding attitude.

In the heatmap shown in Fig. 6, each team member's behavior can be identified. All the students in the group were cognitively disengaged most of the time as they were busy socializing. They were active for a short period. Also, students demonstrated constant communication, team orientation, and a feedback-giving and receiving attitude. It is important to note that S1 and S3 demonstrated some coordination abilities.

VI. Discussion and Implications

Findings from the present study characterized software development team interactions in terms of students' application of knowledge and skills in the form of cognitive engagement and their communication and coordination processes in the form of metacognitive regulation. This finding is significant, as studies focused on teamwork interaction in general [8] and on teamwork engagement in the context of higher education have provided limiting understandings [55]. Furthermore, many studies characterizing teamwork engagement in education settings have primarily focused on science domains [56]. The overall findings from the study suggest a possible relationship between engagement and team regulation. Specifically, cognitive engagement has been associated with students being strategic and self-regulated learners [56]. Thus, the theoretical contribution of the present study provides insights needed on the dynamic and contextual features of

teamwork. Specifically, the study focused on interactions occurring at the team level, as described by the actions performed by individual team members but in relationship with their peers and tied to the specific context of planning their initial project submission [18]. In addition, the coding scheme presented in Appendixes A and B, qualitatively describing the ways students were cognitively engaged and metacognitively regulated, provides new knowledge regarding team interactions in this particular context.

Generally, members of teams for this particular course were cognitively engaged and demonstrated good regulation processes (except for team 4, conforming to Cluster 3). This could be attributed in part to previous courses where students received some form of leadership and teamwork training. However, observable differences in Clusters 1 and 2 were noted for teamwork processes; teams in Cluster 1 demonstrated a higher level of team engagement and regulation than those in Cluster 2. Specifically, team members in Cluster 1 were interactive, constantly communicated their ideas, coordinated the activities, and provided feedback. As team members, they valued each other's opinions while working on the project and demonstrated a high level of team engagement. In contrast, team members in teams forming Cluster 2 demonstrated a moderate level of team regulation as the majority of team members were active while working on the project and provided feedback to one another. It was also noted that one student in a team was passive and did not actively communicate their ideas with other team members. But it is also important to note that the student demonstrated a positive orientation during the whole process. Since students in Cluster 2 were less interactive but active, the overall team engagement level was lower than Cluster 1 students.

As described in ITC theory [18], interaction is one of the most important factors for effective teamwork. Communication between team members has also been identified as important in influencing the social dimensions of teams [16]. Thus, the implications for facilitating effective team interactions in the context of higher education relate to identifying strategies and pedagogical approaches that promote collaboration and communication processes [57]. Research suggests that teamwork interventions effectively develop, support, and improve teamwork processes [34], [35]. Thus, the practical implications of this study suggest that in addition to disciplinary instruction on how to analyze and design systems and how to follow proper software development methodologies [23], students also need to learn and practice teamwork skills. Research has identified that assuming that students in a team will socially interact and collaborate merely because they have been assigned to a group does not mean they will apply teamwork skills [58]. Teamwork interventions that ca improve communication and collaboration processes can take the form of conflict resolution training [57], intercultural training for promoting cultural self-awareness and the influences in teamwork communication [59], [60], and reflection in action approaches to promote team metacognitive processes [61].

Teamwork pedagogy can also be used to orchestrate semester-long projects [62], [63]. Cooperative learning and collaborative learning are two approaches for promoting collaboration through teamwork pedagogy. Cooperative learning diverges from collaborative learning in that cooperative learning involves "a structure of interaction designed to facilitate the accomplishment of a specific end product or goal through people working together in groups" [64], and collaboration is "a philosophy of interaction and personal lifestyle where individuals are responsible for their actions, including learning and respect the abilities and contributions of their peers" [64]. Thus, the practical implications of the present study align with ITC theory by providing a classroom pedagogical approach where students would attempt to learn together, as aligned with cooperative learning, thus focusing more on productive interactions. Furthermore, students could be better guided during teamwork sessions by defining structured and guided teamwork activities to facilitate positive teamwork experiences promoting self-regulated learning [e.g., [65]].

VII. Conclusion, Limitations, and Future Work

This article provided insights into the behavior of teams in an educational setting by describing team interactions in terms of cognitive engagement and metacognitive regulation. Thus, the present study is relevant as it contributes to the understanding of team cognition, particularly in the context of educational settings. Specifically, the clustering method aided in the comprehension of the interplay of cognitive engagement and metacognitive regulation in the form of patterns among software development teams within an educational setting. Clustering also revealed information about how teams approached the assigned tasks, making it possible to ideate ways in which the teaching of teamwork skills can be improved in higher education.

In this work, one limitation was that a measure of overall performance was not taken into consideration, thus limiting the findings to interactions only and not interactions related to high performance. The present study also focused on one interaction at the beginning of the semester; thus, the study does not account for changes in the teams' interactions resulting from developmental effects or the influence of fully integrating or benefiting from scrum practices. Similarly, the study did not document the potential impact of communicating online rather than in person or other moderating factors, including compositional features, structural features, or mediating mechanisms of teamwork. For subsequent studies, researchers and educators could study the relationship between semester-long team engagement, team performance, and the evolution of team interactions over time. Also, the research could investigate differences between cooperative and collaborative approaches and their impact on teamwork performance. Such information would be useful in designing and developing interventions and understanding the impact of interventions on team engagement and regulation. Despite its limitations, the study's findings provide a deep insight into students' interactions and patterns during teamwork

working sessions in the context of educational projects. Findings from this investigation can be used as a foundation for future work in teamwork engagement and regulation, with implications in teamwork mediation and teamwork training.

APPENDIX A
CODES AND DEFINITIONS FOR COGNITIVE ENGAGEMENT, COGNITIVE DISENGAGEMENT, AND DISRUPTIVE BEHAVIORS

Code and Definition	Behavior
Code: Interactive A mode of engagement where there is a dialogue between two or more group members. Dialogues must meet two criteria: (a) both partners' utterances must be primarily constructive (b) a sufficient degree of turn-taking must occur.	1. Debating with one or more group members on an issue related to learning materials.
	2. Discussing or brainstorming ideas, methods, or approaches to solving a problem.
	3. Deciding on the appropriate tools to use for the project.
	4. Mainly characterized by new ideas + sufficient turn-taking between two or more people.
Code: Constructive A mode of engagement where learners generate or produce additional	1. Asking questions in one's own words/ Rephrasing questions.
	2. Taking notes in one's own words as the discussion is ongoing.
externalized outputs, which go beyond the information that was provided in the learning activity. The descriptor of the constructive mode is generative, where learners individually construct new knowledge.	3. Verbally comparing information discussed in the group to prior knowledge or other learning materials/activities.
	4. Drawing analogies from learning materials during group discussion.
	5. Mainly characterized by new ideas produced by ONLY one person.
Code: Active A mode of engagement where some form of motoric action or physical manipulation is undertaken. Learners produce repetitive information through the engagement. With active modes, there is also focused attention on some aspects of learning material.	1. Repeating to/quoting verbatim to group members specific questions about learning material/ learning activity. (verbal)
	2. Taking verbatim notes as group discussion is ongoing. (non-verbal)
	3. Team members not speaking to one another but silently working on tasks to eventually achieve team goals.
	4. Team members seek and provide clarification about assignments.
	5. Team members agreeing to solutions provided by other team members.
	6. Providing suggestions to group members on how to complete processes or tasks.
Code: Passive A mode of engagement where learners only receive information without overtly doing anything.	1. Listening to group members without taking notes.
	2. Listening to group members without uttering a word which contributes to group discussion. Actions that communicate listening include nodding and looking directly into the camera of the video call.
Code: Cognitive Disengagement Engaged in other unrelated activities unrelated or are not paying attention or not staying on task.	1. Leaving the group briefly to attend to other issues (answering phone calls, getting up to get water, etc.)
	2. Present at the group discussion but is absent-minded (includes listening to music, chatting with other group members, etc.)
Code: Disruptive Behavior Learners are engaged in behaviors that are condescending or show disregard for others.	1. Yelling at group members
	2. Ignoring group members
	3. Overpowering conversations
	4. Being late to an ongoing discussion

APPENDIX B
CODES, DEFINITIONS, AND OBSERVED BEHAVIORS FOR METACOGNITIVE REGULATION

Code and Definition	Behavior
Code: Communication Exchanging information actively between two or more members of the team. Communication is the major mechanism & component that links the other teamwork components.	1. Asking questions in one's own words/ Rephrasing questions.
	2. Verbally comparing information discussed in the group to prior knowledge or other learning materials/activities.
	3. Socializing among group members
	4. Discussing topics or having conversations unrelated to group discussion.
Code: Teamwork Orientation Demonstrating attitudes (positive or negative) that team members have to one another, the team task, and their team leadership. Also includes self-awareness as a team member and group cohesiveness.	1. Frowning to communicate frustration, dissatisfaction, or anger (negative attitude)
	2. Sighing to communicate frustration, dissatisfaction, anger, tiredness (negative attitude)
	3. Yelling at team members (negative attitude)
	4. Rolling eyes (negative attitude)
	5. Ignoring group members or talking over group members (negative attitude)
	6. Helping other group members when needed (positive attitude)
	7. Providing reassurance to group members who express doubts, fears, or worries about the project (positive attitude)
	8. Socializing (positive attitude)
Code: Team Leadership Providing direction and structure to team members	1. Deciding the roles and tasks of team members (role allocation).
	2. Listens to the concerns of other team members
	3. Explains to other team members exactly what is needed from them during group discussions.
Code: Monitoring Observing and being aware of activities and performance of other team members.	1. Making references to tasks other team members have completed or plan to complete.
Code: Feedback Giving, seeking, and receiving feedback among team members.	1. Responding to other members' requests for performance information.
	2. Accepting suggestions (positive or negative feedback) offered by other team members.
	3. Seeking and offering clarification for information from group members about the execution of ideas.
	4. Asks for help, input, or guidance with performing a team task when needed.
Code: Backup Behavior Helping other team members to perform their tasks.	1. Helps other team members to correct mistakes.
	2. Volunteers to fill in for another team member who is not able to complete a task (task interchangeability among members).
Code: Coordination Executing activities such that members respond as a function of the behavior of others.	1. Team members engaging in discussion on how to go about their project (planning)
	2. Team members planning on when next to meet.
	Note: The individual who initiates planning is the one who will be considered the coordinator. Note: Successful coordination implies the effective operation of other components of teamwork.

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