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# Understanding the Interactions between the Scrum Master and the Development Team: A Game-Theoretic Approach

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**Abstract:** Scrum methodology is widely used in the information technology (IT) industry for the purposes of team-based iterative software development. However, limited studies have been conducted to explore the nature of interactions between a Scrum Master and other team members and the effect of these interactions on team effectiveness. The aim of this study is to understand the interactions between the Scrum Master and other team members in an educational setting and propose and demonstrate an application of cooperative game theory for the same. Cooperative game theory can model scenarios where other team members can benefit from cooperating. Through the lens of the cooperative game-theoretic model, we investigated the strategies employed by the Scrum Master and other team members when involved in a semi-capstone IT project. Specifically, the study explored the team interaction between a Scrum Master and other team members at three different levels of team effectiveness: least effective, partially effective, and most effective. Our results indicate that a Scrum Master should be active to maximize their payoff as well as the teams' overall payoff. Contrary to this, other team members should be *active* in the most and partially effective teams, while being *passive* in the least effective teams at higher costs of interpersonal relations and the processes. The results of the study represent a novel application of game-theoretic modeling for understanding the Scrum Master and other team member interactions. These results are applicable not just in an educational setting but also to the wider area of software development by identifying the right set of strategies by the Scrum Master, and other team members in order to help IT professionals to maximize their payoff.

**Keywords:** game theory; Scrum Master; teamwork; leadership; team effectiveness; decision making

## 1. Introduction

Teamwork is a critical skill in the information technology (IT) and software development industry for the purposes of team-based iterative software development. An approach used by such professionals to facilitate teamwork skills relate to agile methods such as Scrum [1]. Scrum is a framework that is composed of *roles* performed by team members, *artifacts* in the forms of documentation and deliverables, and *events* consisting of actions a system must perform to communicate and achieve the product delivery [2–4]. Regarding teamwork, the Scrum framework proposes organizing team members into three *roles*: (1) the product owner, serving as the person responsible for communicating between the customer and the development team, (2) the development team, consisting of the group of people doing the work of creating the product, and (3) a Scrum Master, who is the person responsible for supporting the development team and at the same time communicating during meetings, and also facilitating conflict resolution.

As the adoption of Scrum pervades throughout the industry, instructors in higher education have started to adopt Scrum as a pedagogical approach for facilitating cooperative learning (e.g., [5,6]). Cooperative learning, a popular pedagogy, is often employed in learning environments to develop teamwork skills. This pedagogical strategy has proven to be effective and has been used in the classroom for a very long time [7]. Cooperative learning strategies have their foundations in social interdependence theory [8] and help students to work together in small groups to achieve the learning outcome. According to this theory, the individuals interact with each other in a social setting, and the intensity of interaction determines the effectiveness of the outcome [9]. Cooperative learning environments, therefore, allow the students to interact with one another in a social setting, and work together towards a shared learning goal [10,11]. Among the benefits of cooperative learning documented in prior studies [12,13], research has identified that this approach improved diverse outcomes such as academic achievement, promoted higher productivity, and inculcated a sense of care and cooperation.

Previous research focused on studying Scrum teams used a mixed-method approach to analyze the role of a Scrum Master and Scrum team dynamics [14]. The study in [14] conducted a systematic literature review coupled with a case study method to understand the role of the Scrum Master in a Scrum agile environment and emphasized on the importance of Scrum principles to improve overall team performance. In another study, the authors adopted the Scrum-agile framework to develop a collaborative project team [15]. The study used a qualitative case study approach to collect and analyze the impact of the Scrum principles on team collaboration. A third study used semi-structured interviews of the Scrum coaches employed in seven different companies and surveyed 66 team members employed in four different organizations to understand the impact of group maturity in Scrum team development [16]. These previous works suggested the critical role of the Scrum Master and Scrum coaches in improving the overall performance of the Scrum Team.

While the literature on cooperative learning is quite mature, little is known about the effectiveness of coupling it with industry best practices for promoting effective teamwork for software development, such as Scrum. Furthermore, to the best of our knowledge, there is a lack of evidence that demonstrates the application of the game-theoretic model in a Scrum agile environment. Thus, we propose a cooperative game-theoretic model to understand the interactions between the Scrum Master and the development team in an educational setting. In addition, we expect that understanding the interaction and strategies adopted by the Scrum Master and the development team at three different levels of team effectiveness, and determine the methods to improve the overall payoff for the least and partially effective teams. Findings from the study have the potential to assist Scrum Master and team members (in industry and academia) in identifying strategies that could be used in the area of software development to maximize their payoff. The results from the study could also help software industry professionals to develop effective training strategies for Scrum Master and other team members.

Through this study, we intend to explore the following research questions to understand the Scrum Master and development team's interaction, as well as its application in the Scrum-agile framework using the principles of cooperative game theory:

RQ(1) How can we model team interactions between a Scrum Master and other team members using a game-theoretic approach?

RQ(2) What are the strategies adopted by the Scrum Master and other team members at the three levels of team effectiveness in a project-based learning environment using game-theoretic modeling?

According to the Scrum guide [17], the Scrum team is self-organizing and self-managing, responsible for their goal setting and accomplishment, and team members are empowered to make commitments individually, but the team as a whole is responsible for accomplishing the final outcome [18]. We find the application of the game-theoretic model appropriate for this study because game theory is a mathematical approach to modeling the decision-making process of intelligent and rational decision-makers in a cooperative or conflicting situation [19–24]. From the perspective of game theory, a game is a model of social interaction and game-theoretic modeling is the process by which such games are constructed [21]. Games require two or more individuals which are the strategic decision-makers, also known as players [19,21,25]. Prior studies [26,27] have demonstrated the use of game-theoretic models to understand team cooperation and communication.

In a general software development setting, it is the responsibility of the Scrum Master to ensure that the other team members follow the processes and practices that they agreed to as a team. Through this study, we intend to explore and apply a proposed game-theoretic model to understand the interactions between the Scrum Master and other team members, as well as the strategies employed by them as teams, in an undergraduate level semi-capstone software development project. Furthermore, the objective of this study is to explore an association between team effectiveness and the leadership aspect of Scrum Master with other team members in a cooperative project-based learning environment. Investigation of this association will help us to understand the strategies adopted by the Scrum Master and other team members of the most effective teams, which differentiates themselves from a partially or least effective team.

In the subsequent sections, we present a theoretical background about the game theory, Scrum-agile concepts, and their applications in Section 2. This is followed by a description of settings and methods employed to conduct the study in Section 3. We have presented our game-theoretic model in Section 4 and discussed the implications of the model for maximizing payoffs in Section 5. We present our results and interpretations in Section 6, and we also discuss in detail the application and relevance of the results in Section 6. Lastly, Section 7 of the paper provides a conclusion, limitations, and future work.

## 2. Literature Review

### *2.1. Game Theory and Its Application in Education and Teamwork*

Game theory is the research of mathematical models to study the strategies employed when the outcome of an individual's (player's) actions depend on the actions of other individuals [19,21,28]. If an interaction among the individuals is strategic and can be described mathematically, then we call this description a game [28]. Moreover, a game must have four elements. First, is a set of players that are strategic decision-makers. Second is the set of strategies - feasible plans of actions available to the players. The third is a payoff function where a player's payoff depends on the strategies selected by the players in the game. Finally, there is a solution concept that provides a prediction for which strategy each individual will select [21,28]. Game theory is used in many fields to investigate the interactions between the players and find the solutions that aim to maximize the payoff for each player. Therefore, it has extensive applications in many areas, including computer science, biology, economics, social science, systems science, and project management [29–32].

In game theory, games are divided into many different sub-categories, including cooperative and non-cooperative games. In this study, our focus is on cooperative game theory. Cooperative game theory focuses on predicting which joint actions players will form and the resulting total payoffs [33,34]. For example, a game theory-based approach was used in the analysis of cooperative learning in design studios [35]. In their study, the authors focused on the interactions in a design studio environment where they obtained both cooperative and competitive behaviors among the team members. One of the most fundamental games, called the Prisoner's Dilemma [36], is used to analyze the complex behaviors of cooperation and competition in design studios. The results of the game-theoretic analysis propose that inter-group competition, iterative peer assessment, and information transparency are critical factors in promoting cooperative learning in design studios.

Another study by Pitt in [37] used game theory in teamwork to investigate group project assessment by game theory. The author assumed to have three groups of students assigned by the instructor, as poor, average, and bright, who are all working on a project as a team. Team members were supposed to work together and receive better payoff by cooperating in various cases to address the assessment in teamwork using a game-theoretic approach. As a result, the application of game theory shows that the best strategy for the students may not be the one that supports cooperation. In addition, it is suggested that putting students into groups can sometimes disadvantage some students compared to others and cause unfair assessment in teamwork.

The authors in [26] applied evolutionary game theory (EGT) in online study groups to explain students' participation and engagement in collaborative study groups. They aimed to understand and facilitate group collaboration in online learning settings via EGT. They explored the students' perceptions of the pros and cons of collaborative groups and found that the Prisoner's Dilemma could explain the observed lack of participation. Based on the findings, they tried to improve the participation level by mixing the study groups. Burguillo, in [38], focused on using game theory tournaments as a base to implement competition-based learning (CnBL) with other classical learning techniques to increase students' motivation and learning performance. The results suggest that a combination of game theory with the use of friendly competitions (competing against instructor defined code and the code of other students in a tournament environment) increased students' motivation to improve their work and learning performances.

There are limited instances that demonstrate the application of game-theoretic models in educational settings. The literature mentioned above demonstrates a few game theory applications in education, learning, design, and information science to improve team collaboration, but the studies lacked support for their proposed model with actual data. Moreover, the current state of the literature lacks available work in game theory applications for understanding or exploring Scrum Master and team member interactions. Therefore, our work could be a novel contribution to the literature. Our work proposes using real data collected by analyzing the student team retrospectives, and specifically focuses on the interactions between the Scrum Master and other team members within an educational setting when involved in a semi-capstone group project.

### 2.2. Concept of Scrum, Scrum Master, Leadership and Team Effectiveness

Since the study intends to understand the interaction between the Scrum Master and the development team, it was important to understand the basics of Scrum-agile methodology [39,40]. The importance of Scrum can be tied to its adoption in industry. A survey conducted in 2014 with responses from 126 geographically distributed companies showing that over 76% of the organizations had adopted Scrum with varying degrees of success [41]. Scrum was developed at Easel Corporation in 1993 by Jeffrey Sutherland for use in their software teams with the primary goal of delivering quality software in small time boxes referred to as sprints [42]. According to [17], Scrum is "a framework within which people can address complex adaptive problems, while productively and creatively delivering products of the highest possible value". The Scrum product development approach involves teams working together as a unit in an iterative and incremental fashion [43]. The agile-Scrum framework allows the developers to share their knowledge, inculcate a sense of cooperation, and allows them to become a self-managed team.

There are only three roles in Scrum: (1) product owner; (2) development team; and (3) Scrum Master [44]. The product owner determines the release plans and defines the list of requirements referred to as the product backlog. The development team is responsible for implementing the requirements from the product backlog in an iterative, incremental, and self-managed fashion. The Scrum Master is responsible for the entire Scrum process and for teaching Scrum to everyone involved in the project [44]. The Scrum Master can be referred to as a coach or the facilitator of the project [18] or in simple words, the Scrum Master is the person who ensures that the team adheres to the Scrum rules, values, and agile principles [45].

Since the Scrum teams are self-managed, the role of the Scrum Master is that of a coach, since each member shares the responsibility of the project execution and works cooperatively to execute the final project [46]. The Scrum process suggests a series of stages for planning, implementing and delivering a product [2]. Following the execution of a sprint, a meeting is held to review progress, raise and resolve issues, and to add to or update items in the product backlog. The review process can be formalized using structured retrospectives which further allows teams to reflect on positive and negative aspects of a sprint while committing to improve on the next sprint [5]. The release or closure phase prepares the product that has been developed for release and this can include further testing, marketing material preparation, and training material development [2]. Figure 1 explains the scrum process in detail.

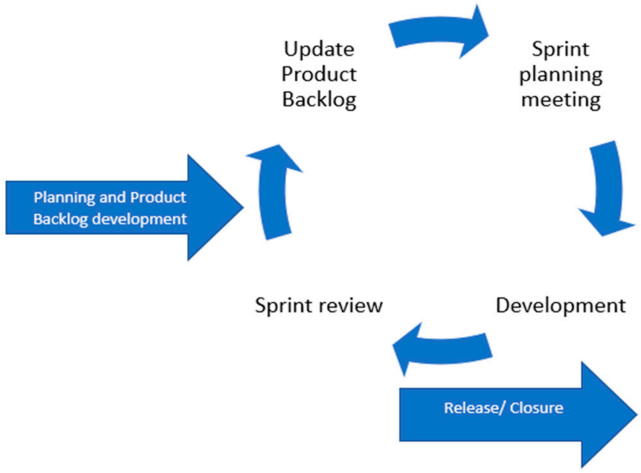


**Figure 1.** Scrum process illustration.

The coaching role of the Scrum Master appears to be perceived as different from their analog, a project management, in other more traditional software development methodologies. For instance, a study by Yang et al. [47] compared the perception of project managers regarding agile approaches of software development and the role of a project manager. The study revealed that project managers preferred an agile method of software development than the traditional waterfall method. In addition, their study revealed that project managers found a transformational leadership style appropriate for successful software development in an agile environment [48].

The prior studies [48–51] revealed several characteristics of transformational leadership such as self-management, collaboration, collective decision making, shared vision, adaptability, encouraging new ideas, and inspirational motivation. These characteristics make the transformational leadership style appropriate for the agile Scrum approach. Since we plan to see the role of Scrum Master in an educational setting, we used the transformational leadership traits proposed by Astin and Astin [52] for a transformational student leader. The study in [52] identified five traits that are important for a student in order to become a transformational Scrum Master: shared purpose, commitment, collaboration, division of labor, and competence. Furthermore, the study also stated that leadership is not a designated trait; rather, it is a shared belief by a group of people who share a common concern and work together towards a purposeful change that results in a positive outcome [52]. The five transformational leadership traits served as the foundation for developing our leadership rubrics to measure the leadership skills of the Scrum Master.

Similar to industry contexts, in educational contexts the role of the Scrum Master is crucial for the Scrum team as the Scrum Master serves as a coach and facilitator of the team. Since the agile-Scrum framework has been widely used in the industry applied to the agile-Scrum principles on a semi-capstone course project that guided students to develop a prototype as the final course deliverable. Prior studies [5,53–55] confirmed that the agile-Scrum approach had been widely used to teach software development in university classrooms. A study by Magana et al. [5] led the course that followed an agile-Scrum approach to teach students software development when working as a team. The application of the agile Scrum approach helped students to effectively design and analyze the software solution for their capstone project, and also helped them to reflect on their team dynamics. We further narrowed down our focus on the role of the Scrum Master, the interaction between the Scrum Master and other team members, and the impact of their interaction on team effectiveness [56].

Furthermore, to understand the impact of the interaction between the Scrum Master and development team, we evaluated team effectiveness from the perspective of the Goals, Roles, Processes, and Interpersonal Relations (GRPI) model. The GRPI model of team effectiveness was proposed by Beckhard in [57], and measures the team effectiveness as an aggregate of goals, roles, processes, and interpersonal relationships that the team demonstrates. The model is sequential and interdependent, as Rubin et al. [58] proposed that it is of utmost importance for the teams to define their goals, by explicitly stating the main purpose. After that, the goals are defined; the next task is to allocate roles, as it is important to detail who will do what. Subsequently, the processes are worked out. Processes refer to the planned workflow that each team member will follow to execute the task; this role involves decision making on the part of all team members. Lastly, it is crucial to define the interpersonal relationship that entails how all the team members handle communication, collaboration, trust, and conflict management.

Prior studies have demonstrated this model being used in multiple sectors to measure team effectiveness. For instance, Raue et al. [59] used this model in combination with the technical, political and cultural (TPC) dimensions of business operations to develop a robust framework of team effectiveness and organizational effectiveness [60]. The combination helped the teams to function in an organized manner that further resulted in higher performance. In another study by Duckworth [61], the GRPI model was used to improve team cohesion in a global virtual team setting. The study found that GRPI was an effective approach to enhance team effectiveness, and further demonstrated how project managers, in dispersed settings, who were trained on the principles of the GRPI model drastically improved the overall performance of the company as a whole. Carlock [62], utilized the team effectiveness model to develop assessments for their employees to measure team cohesion. Carlock's study emphasized the role of the leader and the team members in setting the goals, roles, interpersonal relations, and group processes. The study developed two assessments to measure the role of leader and team members on the GRPI framework.

In this study, we used the GRPI framework as the basis to evaluate team effectiveness. Since the prior studies by [60–62] already demonstrated the impact of this framework in evaluating team effectiveness, we also intend to explore the GRPI framework to understand the team effectiveness in an Scrum agile environment. We also developed a rubric for assessing team effectiveness (see Section 3.3.). Furthermore, the scores were analyzed statistically, and the teams with the highest score, median score, and lowest score were selected for the purpose of experimenting using game-theoretic modeling.

## 3. Methods

The study developed and applied a game-theoretic model to understand the strategies adopted by the Scrum Master and other team members in a project-based learning environment. In this study there were predominantly two players: (1) Scrum Master and (2) other team members. Game theory was therefore used to find the best strategies that aim to maximize the payoff for each player. Specifically, our research questions were: (1) how can we model team interactions between a Scrum Master and other team members using a game-theoretic approach, and (2) what strategies are adopted by the Scrum Master and other team members at the three levels of team effectiveness in a project-based learning environment using game-theoretic modeling?

The specifics of our game-theoretic model and analytical procedures are described in the following sections.

### *3.1. Participants and Context*

#### 3.1.1. Setting

This research study was set in a sophomore-level systems analysis and design course set in a large midwestern university. The data were collected in the Fall 2019 semester. The majority of the students enrolled in this course were pursuing a major or minor in computer and information technology and were sophomore-level in student-standing. Students enrolled in this course, as a prerequisite, have already completed an introductory systems development course. They have worked in teams as part of a design thinking course, and have experience with an object-oriented programming language through either coursework or practical experience such as internships.

The systems analysis and design course was designed to incorporate theory-based applied learning through a Scrum-based team-project [5]. The course covered techniques and approaches to discover and model the requirements of a software system. Unified Modeling Language (UML) was used to construct software models. The team-project required students to iteratively design a system solution and construct a functional prototype.

The Scrum-based team-project was designed with the goal of getting students to apply conceptual knowledge through the process of requirements, modeling, and prototype development. Students worked in teams of three to five members and utilized class meetings to elicit feedback from the instructional team on their project progress. The project was divided into four milestones, and the goal was to develop the final solution iteratively across these milestones. There was a total of 114 students enrolled in this course. The 114 students enrolled in the course were divided into 23 teams. Students in each team would take on the role of a development team member, product owner, and Scrum Master. The product owner was responsible for managing the product backlog and the project Gantt chart. The Scrum Master was responsible for handling team communication and conflict resolution. The roles of the product owner and Scrum Master were rotated through each milestone. Students prioritized requirements in the provided backlog and organized them into user stories. A team retrospective was a mandatory deliverable for each milestone where teams reflected on how they tackled setting goals, assigning roles for team-members, and defining group processes. In addition, teams reflected on the positive aspects of each milestone in terms of what went well and the points of improvement for future milestones. Approval was obtained from the university's institutional review board (IRB) to collect these data.

#### 3.1.2. Participant Selection for the Study

Team retrospectives of 23 teams (each team composed of four to five members) were analyzed and scored using the GRPI rubrics mentioned in Table 2 to arrive at three overall categories of team effectiveness—most effective, partially effective, and least effective (see Section 3.2 for details). The GRPI rubric is scored on the scale of 0 (minimum) to 2 (maximum). One team from each category was selected for the subsequent leadership scoring based on the transformational leadership framework and game-theoretic modeling. The rationale for selecting one team from each category was that each of those teams were representative of each level of effectiveness. The team with the highest effectiveness score was considered the representative for the most effective team, the team with the median effectiveness score was considered as the representative of the partially effective teams, and the team with the lowest effectiveness score was considered the representative of the least effective teams.

### *3.2. Data Collection*

For this study, the team retrospectives from all 23 teams were used as the data collection method. Each team was assigned a pseudonym to protect the identity of the students. Teams were required to submit retrospectives as a deliverable for each milestone with a total of four milestones and one more for the final project. All teams were provided with a team retrospective template with the following prompts in Table 1 below:

**Table 1.** The link between the Goals, Roles, Processes, and Interpersonal Relations (GRPI) model and team retrospective questions.

| Theme | Definition | Team Retrospective Questions |
| --- | --- | --- |
| Goals | Explanation of planning or overall vision for the current milestone. | • How did you plan the organization of work for the milestone? |
| Roles | All team members must know what part they play, what is expected, and how they are held accountable and responsible. | • What were the team members' roles?<br>• How were activities assigned to each team member, and what was the justification for that? |
| Processes | Explanation about procedures that the team has to follow, in terms of workflow or review, for current milestone or improvements to be made for future milestones | • What are areas or sections of the milestone that you just completed you think could be improved?<br>• What are the aspects you think can be done better for the next milestone in terms of team performance?<br>• What are the possible concerns?<br>• What do you think as a team was particularly good about the milestone you just completed? |
| Interpersonal Relationships | Explanation about quality of communication and collaboration among team members; any reference to communication platform; team participation; conflict management, and resolution. | • How was the communication handled among team members?<br>• What aspects of the team coordination/collaboration went well in this milestone?<br>• What aspects of the team coordination/collaboration went wrong in this milestone? |

### 3.3. Data Scoring and Analysis (Rubrics and Scoring)

Data analysis was divided into two phases. In the first phase, the milestone retrospectives of all 23 teams were analyzed based on the Goals, Roles, Processes, and Interpersonal Relations (GRPI) framework [58]. The scoring of the retrospectives was conducted based on the rubrics detailed in Table 2. The overall score for each milestone was calculated by adding the scores obtained for goals, roles, processes, and interpersonal relations. This was then used to calculate the total mean scores obtained by each team across all the four milestones. Based on the percentile distribution of the total mean scores, teams were grouped into the categories of most effective (>66th percentile), partially effective (≤66th percentile), and least effective (≤33rd percentile). Of the 23 teams, six teams were classified as least effective, seven teams were classified as partially effective, and ten teams were classified as most effective.

In the second phase, teams with the highest score, median score, and lowest score were selected for further analysis. Further scoring was performed on the retrospectives of those chosen teams based on the transformational leadership framework. Rubrics were adopted from Astin and Astin [52] to score the retrospectives. The rubric elements and levels are detailed in Table 3.

**Table 2.** Rubric representing the definition and scores for each level.

| Criterion | 0 | 1 | 2 |
|---|---|---|---|
| Goals | Did not address the overall plan for the current milestone in terms of goals and/or organization | Addressed goals and organization of the team in an insufficient manner | Comprehensively addressed the goals and organization of the team |
| Roles | Did not delineate the roles and responsibilities of team members | Vaguely defined the roles and responsibilities of some team members or did so for all team members but was lacking clarity | Explicitly delineated roles and responsibilities of every team member |
| Processes | No detailed explanation for procedures the team has to follow | Vaguely defined procedures for the team to follow | Explicitly defined procedures for the team to follow |
| Interpersonal Relationships | Exhibited poor quality of communication and collaboration | Exhibited moderate quality of communication and collaboration | Exhibited Excellent quality of communication and collaboration |

**Table 3.** Leadership rubric representing the constructs, definitions, and scores for each level.

| Construct | Source Definition | 0 | 1 | 2 |
|---|---|---|---|---|
| Shared Purpose | Are we really clear about what the group is supposed to be doing? Are we all in agreement about this? | No references to shared purpose or goals of the group | Vaguely defined the shared purpose or goals of the group | Clearly defined the shared purpose or goals of the group |
| Commitment | Am I putting out enough effort? Am I doing my fair share? | No references to commitment to perform specific work in the next milestone | Briefly discussed plans for future improvement | Detailed specific instances of future improvement |
| Collaboration | Are we all working together, or are some of us competing with each other? | No references to collaboration as a group | Vaguely detailed strategies for and/or effectiveness of collaboration as group | Detailed strategies used for and the effectiveness of collaboration |
| Division of Labor | Am I clear about what I'm supposed to be doing in the group effort? Am I clear about what the others are expected to do? | No references to assignment of work or delineation of responsibility | Briefly discussed roles and responsibilities of team members | Clearly delineated roles and responsibilities of team members |
| Competence | Do I know what I need to know in order to play my part in the group? Have I done my "homework"? | No references to how well the team performed overall in a milestone | Briefly discussed overall competence of the team without little to no specifics | Discussed overall competence of the team in terms of what was done well and what could have been improved |

### *3.4. Validity and Reliability (Cohen Kappa)*

In both phases of the data analysis, another researcher coded 20% of the retrospectives to ensure inter-rater reliability. Inter-rater reliability given by Cohen's Kappa was calculated in both phases. In both phases, Cohen's Kappa was calculated as 0.673, indicating that the raters agreed on the majority of the coding [63].

## 4. Game-Theoretic Model

This research study is not a quasi-experimental or experimental in nature. A game-theoretic setting was assumed. Suppose we have a team, including a Scrum Master and other team members (more than two people) who are interacting with each other to work as a team on a project. We assume that the Scrum Master and other team members (OTM), which we call players henceforth, can have two strategies: (1) being active, or (2) being passive, during the teamwork. An active strategy is a strategy that requires a player to actively contribute to and attend meetings while engaging in a discussion pertaining to the project. On the contrary, a passive strategy entails players not proactively contributing to team meetings nor engaging with the group. Each strategy has its own benefit or value for each player. At the same time, there are costs associated with the time and effort they are spending while working as a team, as well as the cost of interpersonal relations and processes, which include the costs associated with all team members' conflict and extra effort in the processes, in the game-theoretic model setting. We aim to explore the best strategies to maximize the Scrum Master and other team players' effectiveness during the teamwork processes using game-theoretic modeling.

We explored the interactions between a Scrum Master and other team members as a two-player game with active and passive being the players' distinct strategies. We made the assumption based on the cooperative learning that the players (Scrum Master and other team members) are willing to cooperate either being active or passive over a project as a team to maximize their overall team effectiveness as an outcome of their interaction. Moreover, we assume that the players who chose to use either an active or passive strategy will pay the cost of interpersonal relations and processes. Additionally, we assume that the effectiveness of the teamwork processes using an active or passive strategy adds up to 1, as these are the only two strategies available to the players. In this $2 \times 2$ game, we use the parameters shown in Table 4, which illustrates the parameters used to develop the game-theoretic model. They were defined based on the benefits and costs of being a Scrum Master and other team members when working on a project as a team.

**Table 4.** Definition of the parameters

| |
|---|
| $L$: Benefit of being a leader for a Scrum Master (leadership skills) |
| $P$: Benefit of team effectiveness during a project, $P > 0$ |
| $\alpha$: Effectiveness of teamwork processes using an Active strategy, $0 < \alpha < 1$ |
| $\beta$: Effectiveness of teamwork processes using a Passive strategy, $0 < \beta < 1$, $\alpha + \beta = 1$ and $\alpha > \beta$ |
| $C$: Cost of interpersonal relations and processes |

To explore the interactions which are the measure of the cooperation between a Scrum Master and other team members using active and passive strategies, we created a payoff matrix. In the payoff matrix $A$, represented in Table 5, the element in row $i$ and column $j$, $(a_{ij})$ shows the payoffs to the individuals who use strategies $i$ and $j$ against each-other. Table 5 shows the payoff matrix $A$ with active and passive strategies. In matrix $A$, each entry has two elements separated by a comma. The first element (left-hand side of the comma) represents the payoff to the row player (often regarded as the first player). The second element (right-hand side of the comma) represents the payoff to the column player (often regarded as the second player). For example, if we look at $a_{12}$, an element of the payoff matrix $A$ shown in Table 5, which is the payoff to the row player (Scrum Master) who uses active as a strategy and receives $L + \alpha * P - C$, compared to a column player (other team members) who uses passive as a strategy and receives the payoff of $\beta * P$.

**Table 5.** Payoff matrix $A$ for $2 \times 2$ (Scrum Master vs. other team members (OTM)) game.

| . | **Active** | **Passive** |
|---|---|---|
| Active | $L + P - C,\ P - C$ | $L + \alpha * P - C,\ \beta * P$ |
| Passive | $\beta * P,\ \alpha * P - C$ | 0, 0 |

If a row player who uses an active strategy interacts with a column player who also uses an *active* strategy, the row player gets the benefit of being a leader, so his/her leadership skills will increase while benefiting from the teams' effectiveness as well. On the other hand, the row player will pay the cost of interpersonal relations and the processes. Therefore, the expected payoff of a row player who employs an active strategy becomes $L + P - C$. Similarly, the expected payoff of a column player who employs an active strategy becomes $P - C$ as they will only benefit from the teams' effectiveness during a team project but will still pay a cost of interpersonal relations and processes as a column player.

### 4.1. Game-Theoretic Analysis

In game theory, a Nash equilibrium, which is a set of strategies, one for each player, such that no player has the incentive to change his or her strategy given what the other players are doing is used to analyze the game-theoretic models [64]. Simply, if no player can gain benefit by changing their own strategy while the other players keep theirs unchanged, then the current set of strategies is the Nash equilibrium of the game. In order to analyze the game-theoretic model, we developed the payoff matrix in Table 5. So, (Active, Active) is a Nash equilibrium if the expected payoff of playing Active against Active is greater than that of playing Passive against Active and Active against Passive.

Thus, if the Equation (1) below holds,

$$L + P - C > \beta * P \text{ and } P - C > \beta * P \tag{1}$$

which reduces to

$$C < \alpha * P \tag{2}$$

then (Active, Active) is a Nash equilibrium, which means it is the best strategy pair for both players to play (Active, Active). In order to simplify the analysis, let us divide the Equation (2) by $P$, then we get the following Equation (3) below:

$$\frac{C}{P} < \alpha \text{ where } 0 < \alpha < 1 \tag{3}$$

Let us denote $\gamma_1 = \frac{C}{P} > 0$, $\gamma_2 = \frac{L}{P} > 0$, which represents the cost-team effectiveness and leadership-team effectiveness ratios, respectively. Then Equation (3) can be rewritten as

$$\gamma_1 < \alpha \tag{4}$$

On the other hand, if

$$L + \alpha * P - C < 0 \textit{ and } \alpha * P - C < 0 \tag{5}$$

then (Passive, Passive) is a Nash equilibrium.

So, Equation (5) implies

$$C > L + \alpha * P \text{ and } C > \alpha * P \tag{6}$$

then it is best for both players to play *Passive* strategy in the game.

Similarly, dividing Equation (6) by $P$ and replacing $\frac{C}{P}$ by $\gamma_1$, $\frac{L}{P}$ by $\gamma_2$ we get the following Equation (7) below

$$\gamma_1 > \gamma_2 + \alpha \tag{7}$$

Moreover,

$$L + \alpha * P - C > 0 \textit{ and } \beta * P > P - C \tag{8}$$

then (Active, Passive) is a Nash equilibrium. From Equation (8), we get the following inequality as a condition for (Active, Passive) to be a Nash equilibrium. If the cost is in between the following values

$$\alpha * P < C < L + \alpha * P \tag{9}$$

then the Scrum Master should be active and other team members need to be passive to maximize their payoffs. Again, diving (9) by $P$ and replacing $\frac{C}{P}$ by $\gamma_1$, $\frac{L}{P}$ by $\gamma_2$ , we get the following equation

$$\alpha < \gamma_1 < \gamma_2 + \alpha \tag{10}$$

Lastly, if

$$\beta * P > L + P - C \text{ and } \alpha * P - C > 0 \tag{11}$$

then (Passive, Active) is a Nash equilibrium. From Equation (11), we get the following condition

$$L + \alpha * P < C < \alpha * P \tag{12}$$

for a Scrum Master to play a passive role and other team members to play an active role to maximize their payoffs. Dividing (12) by $P$ and replacing $\frac{C}{P}$ by $\gamma_1$, $\frac{L}{P}$ by $\gamma_2$ , we get the following equation

$$\gamma_2 + \alpha < \gamma_1 < \alpha \tag{13}$$

From the Equations (4), (7), (10), and (13), we get the following Nash equilibrium diagram (see Figure 2), which represents the regions and conditions where all possible strategy pairs are in equilibrium. It is also seen in Figure 2 that it is possible that in some regions under various conditions, all three strategy pairs can be Nash equilibrium.

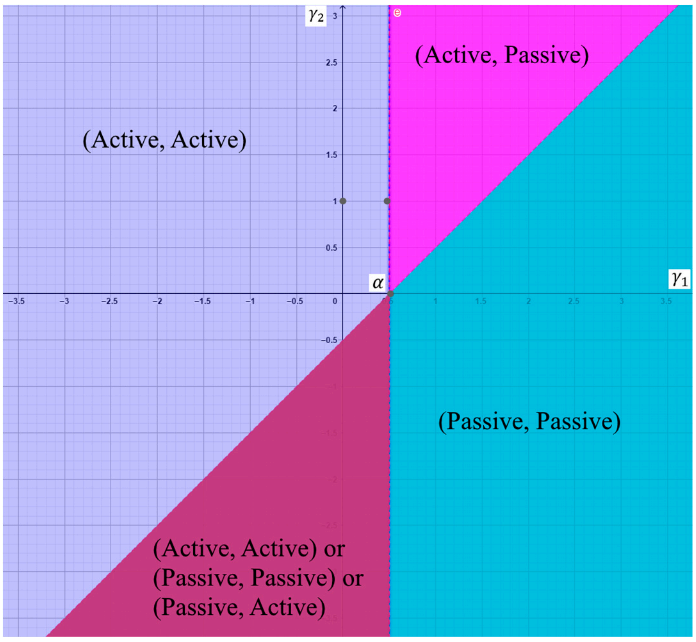


**Figure 2.** Nash equilibrium diagram for the $2 \times 2$ game between the Scrum Master and other team members with $\alpha$, $\gamma_1$ and $\gamma_2$ parameters.

## *4.2. Parameters in the Model*

### 4.2.1. Team Effectiveness (P)

The team retrospectives for all 23 student teams and all the four milestones were scored based on the team effectiveness rubrics developed based on the GRPI framework, as shown in Table 1. The final team effectiveness score was the sum of the scores that students obtained for goals, roles, processes, and interpersonal relationships in each milestone.

Specifically, for this study, we selected three teams from each effectiveness category: least effective, partially effective, and most effective. The parameters for choosing each team were: the team with the highest effectiveness score was considered the representative for the most effective team, the team with the median effectiveness score was considered as the representative of the partially effective teams, and the team with the lowest effectiveness score was considered the representative of least effective teams. The three teams served as the sample for the game-theoretic modeling. The results of the modeling are described in Section 5.1 for the least effective team, Section 5.2, for the partially effective team and Section 5.3 for the most effective team.

#### 4.2.2. Leadership (L)

Furthermore, to calculate the leadership variable (L), the team retrospectives for the three selected teams, from each effectiveness category, were analyzed based on the transformational leadership rubric (see Table 3). The rubric was used to score the leadership traits of the Scrum Master in each milestone. The leadership score for each milestone (l) was the total of the scores obtained by the Scrum Master for the five traits: shared purpose, commitment, collaboration, division of labor, and competence. The final leadership score (L) was the grand total of the milestone leadership score (l) obtained by each team.

#### 4.2.3. Cost (C)

The cost C was calculated for the three teams from each effectiveness category, by taking the complement value of the processes and interpersonal relationships scores using the GRPI rubrics. The cost was defined as the conflict faced by the team in terms of interpersonal relations and group processes. Therefore, the cost scores for each team was calculated as the following:

$$C = 1 - (IP\ score + Processes\ score)/(Highest\ possible\ total\ score\ for\ IP + Processes)$$

All the team effectiveness, leadership, and cost scores were standardized for the purpose of analysis. Figure 3 illustrates the data-scoring and analysis processes followed in this study.

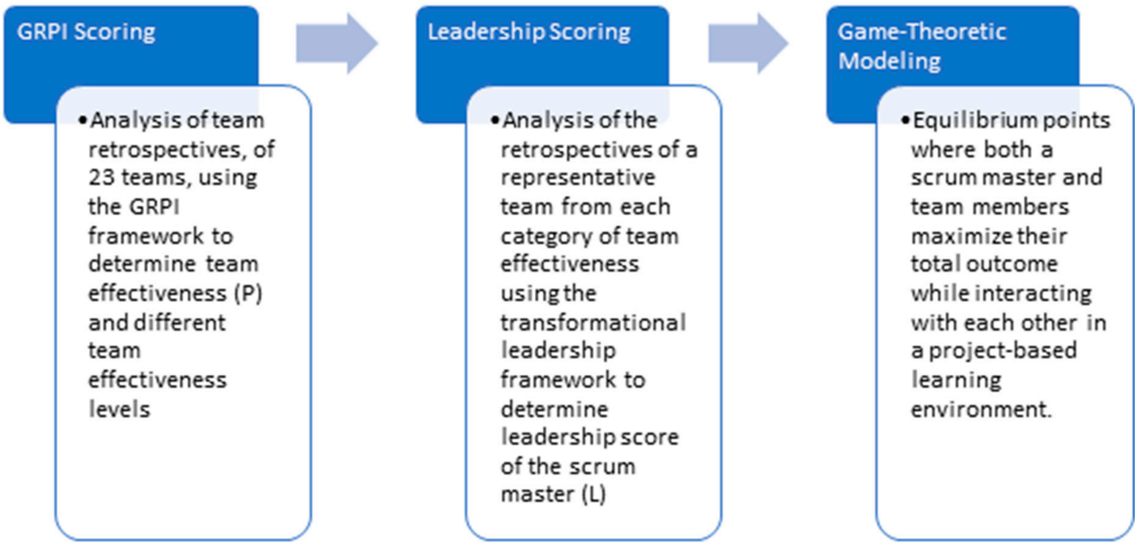


**Figure 3.** Data scoring and analysis flow-chart detailing the steps at each stage.

## 5. Results and Interpretation

In this section, we mapped the real data to the parameters we defined in the game-theoretic model. The team retrospectives were scored to calculate the leadership parameter ($L$), team effectiveness parameter ($P$), and cost of interpersonal relations and processes ($C$). In the following subsections, we represent one example from each team effectiveness levels for a variety of different scenarios. The game-theoretic model and its analysis answer our first research question, and Sections 5.1–5.3 answer our second research question.

### *5.1. Least Effective Team Conditions*

For the least effective team, we chose the team with the lowest score in terms of goals, roles, interpersonal relations, and processes (GRPI), and based on their scores, and we assigned a pseudonym for the team. We called it the least effective team, and we identified it as team AA. Based on the rubrics used, the Scrum Master's leadership score was $L = 0.475$, team effectiveness score $P = 0.44$, and cost of interpersonal relations and processes $C = 0.5$. Note that the scores were standardized between 0 to 1 for the ease of calculation. Thus, when we plugged them into the payoff matrix in Table 5, we found the following:

From Table 6, we see that choosing an *Active* strategy is much better than choosing a passive strategy for a row player (0.415 > 0.198). On the other hand, being passive has much greater payoff than being active for a column player (0.198 > −0.06). Therefore, the (Active, Passive) strategy pair is a Nash equilibrium for the least effective teams with the above conditions. This finding suggests that whenever the leadership and team effectiveness scores were low, but the cost and the effectiveness of teamwork processes were high. Then a Scrum Master should be active, other team members need to be passive for the least effective team condition. Similarly, for various values of $\alpha$ and $\beta$, we get the following results below. Tables 7 and 8 also show that (Active, Passive) is a Nash equilibrium which is written in bold for the least effective teams with high values of $\alpha$ and lower values of $\beta$.

**Table 6.** Payoff matrix A for 2 × 2 (Scrum Master vs. OTM) game for the least effective team with $L = 0.475, P = 0.44, C = 0.5, \alpha = 0.55, \beta = 0.45$.

| | **Active** | **Passive** |
|---|---|---|
| Active | 0.415, −0.06 | **0.217, 0.198** |
| Passive | 0.198, −0.258 | 0, 0 |

**Table 7.** Payoff matrix A for 2 × 2 (Scrum Master vs. OTM) game for the least effective team with $L = 0.475, P = 0.44, C = 0.5, \alpha = 0.75, \beta = 0.25$.

| | **Active** | **Passive** |
|---|---|---|
| Active | 0.415, −0.06 | **0.305, 0.11** |
| Passive | 0.11, −0.17 | 0, 0 |

**Table 8.** Payoff matrix A for 2 × 2 (Scrum Master vs. OTM) game for the least effective team with $L = 0.475, P = 0.44, C = 0.5, \alpha = 0.95, \beta = 0.05$.

| | **Active** | **Passive** |
|---|---|---|
| Active | 0.415, −0.06 | **0.393, 0.022** |
| Passive | 0.022, −0.082 | 0, 0 |

As seen above in Tables 6–8, for the least effective teams, our results suggest for a Scrum Master to play an active role and other team members to play passive roles to maximize their own payoffs.

### *5.2. Partially Effective Team Conditions*

For the partially effective team, we chose the team with a median score in terms of goals, roles, interpersonal relations, and processes (GRPI). Given these scores, we assigned a pseudonym for the team as partially effective, identified as team AB. Based on the rubrics we used for a Scrum Master's leadership score was $L = 0.675$, team effectiveness score $P = 0.72$, and cost of interpersonal relations and processes $C = 0.25$. Thus, when plugging them into the payoff matrix in Table 5, we find the following:

From Table 9, we see that being active is much better than being passive for both a row and column players (As the payoff of being active is much bigger than being passive for a row player which is 1.145 > 0.324 and similarly the payoff of being active is much bigger than being passive for a column player that is 0.47 > 0.324. So, this implies that (Active, Active) is a Nash equilibrium. This suggests that whenever the leadership score is relatively high, and team effectiveness is high, the cost is low, or the effectiveness of teamwork processes for being passive is high, then a Scrum Master should be active, other team members to be active for a partially effective team. Similarly, for various values of $\alpha$ and $\beta$, we get the following cases.

**Table 9.** Payoff matrix A for $2 \times 2$ (Scrum Master vs. OTM) game for the partial effective team with $L = 0.675,\ P = 0.72, C = 0.25,\ \alpha = 0.55,\ \beta = 0.45$.

| | Active | Passive |
|---|---|---|
| Active | **1.145, 0.47** | 0.821, 0.324 |
| Passive | 0.324, 0.146 | 0, 0 |

As seen above in Tables 9–11 for the partially effective team, we suggest for a Scrum Master to be active and other team members to be active to maximize their own payoffs.

**Table 10.** Payoff matrix A for $2 \times 2$ (Scrum Master vs. OTM) game for the partial effective team with $L = 0.675,\ P = 0.72, C = 0.25,\ \alpha = 0.75,\ \beta = 0.25$.

| | Active | Passive |
|---|---|---|
| Active | **1.145, 0.47** | 0.965, 0.18 |
| Passive | 0.18, 0.29 | 0, 0 |

**Table 11.** Payoff matrix A for $2 \times 2$ (Scrum Master vs. OTM) game for the partial effective team with $L = 0.675,\ P = 0.72, C = 0.25,\ \alpha = 0.95,\ \beta = 0.05$.

| | Active | Passive |
|---|---|---|
| Active | **1.145, 0.47** | 1.109, 0.036 |
| Passive | 0.036, 0.434 | 0, 0 |

### *5.3. Most Effective Team Conditions*

For the most effective team, we choose the team with the highest score in terms of goals, roles, interpersonal relations, and processes (GRPI). Based on these scores, we assigned a pseudonym for the team as the most effective team identified as AC. Based on the rubrics we used for Scrum Master's leadership score was $L = 1$, team effectiveness score $P = 1$, and cost of interpersonal relations and processes $C = 0$. Thus, when mapping these numbers into the payoff matrix in Table 5, we find the following:

From Table 12, we see that (Active, Active) is a Nash equilibrium. This suggests that whenever the leadership score (L = 1), and team effectiveness ($p = 1$) is high, and the cost is zero (C = 0), then it is best for all players to choose an active strategy to maximize their total payoff. Similarly, for various values of $\alpha$ and $\beta$, we get the following cases.

**Table 12.** Payoff matrix A for $2 \times 2$ (Scrum Master vs. OTM) game for the most effective team with $L = 1, P = 1, C = 0,\ \alpha = 0.55,\ \beta = 0.45$.

| | Active | Passive |
|---|---|---|
| Active | **1, 1** | 1.55, 0.45 |
| Passive | 0.45, 0.55 | 0, 0 |

As seen above in Tables 12–14 for the most effective team, we suggest for a Scrum Master to be active and other team members to also be active to maximize their payoffs.

**Table 13.** Payoff matrix A for $2 \times 2$ (Scrum Master vs. OTM) game for the most effective team with $L = 1,\ P = 1, C = 0,\ \alpha = 0.75,\ \beta = 0.25$.

| | Active | Passive |
|---|---|---|
| Active | **1, 1** | 1.75, 0.25 |
| Passive | 0.25, 0.75 | 0, 0 |

**Table 14.** Payoff matrix A for 2 × 2 (Scrum Master vs. OTM) game for the most effective team with $L = 1$, $P = 1, C = 0$, $\alpha = 0.95$, $\beta = 0.05$.

| | **Active** | **Passive** |
|---|---|---|
| Active | **1, 1** | 1.95, 0.05 |
| Passive | 0.05, 0.95 | 0, 0 |

## 6. Discussion

In this study, we focused on the strategic interactions between a Scrum Master and other team members in a project-based learning environment using a game-theoretic modeling approach. We explored the best strategies for both a Scrum Master and other team members under various conditions. In addition, we used real data and demonstrated an application of game theory in teamwork to support our findings.

Our main contribution is the development of a game-theoretic model that explains the team interactions between a Scrum Master and other team members, answering our first research question. As the current literature lacks applications of game theory for understanding or exploring Scrum Master and team member interactions. Thus, our work could be a novel contribution to the literature. We also investigated a solution concept (Nash equilibrium) for teams with different levels of effectiveness, including; most effective, partially effective, and least effective, all in terms of goals, roles, processes, and interpersonal relations. The model helped us to determine strategies that teams at three levels of effectiveness could adopt to maximize their overall payoff. Moreover, the model also looked at the role of the Scrum Master as a leader. The idea of leadership is derived from the theory of transformational leadership [47], as the Scrum team is a self-managed team [17], the leader (Scrum Master) needs to be adaptable and flexible while promoting collaboration to maximize the overall team effectiveness [47,49,65]. This emphasizes the importance of a Scrum Master's activeness as a leader while working with the team on a project as it is also suggested as a result of the game-theoretic model we have developed. Moreover, the Scrum team can maximize their effectiveness and the leader can be considered effective if the team as a whole can minimize the cost of interpersonal relations and processes among the team members [65]. Furthermore, our findings suggest that the cost of interpersonal relations and processes due to interaction among the team members was high in the least effective teams as compared to the partially effective and most effective teams. The most effective teams in our case maximized their overall team effectiveness and leadership by minimizing the cost of interpersonal relations and processes.

Teams can minimize the cost of interpersonal relations and processes by maintaining good interpersonal relations and defining the process or workflow adequately. As it was also suggested in [66], teams can improve their performance and satisfaction and reduce the cost of interpersonal relations by following three conflict resolution strategies; (1) focusing on the content of interpersonal interactions rather than delivery style, (2) clearly discussing the reasons behind any decisions reached during the processes, and (3) making an appropriate role assignment based on the team members' expertise [66]. The model also finds its application in the software development industry. The model can help the Scrum Master and team members to (a) develop strategies such as defining the goals, roles, interpersonal relations and group processes, and (b) define the leader's role, in advance so that the cost of interpersonal relations and processes can be minimized and the overall payoff can be maximized.

To answer our second research question, we also demonstrated an application of a game-theoretic model using real data from a sophomore-level system analysis and design course. Moreover, we determined the impact of the cooperation between the Scrum Master and team members on overall team effectiveness. The application of the model in the educational setting added a new method to evaluate team interaction. The emphasis on the characteristics of transformational leadership, along with pre-defined team effectiveness parameters such as goals, roles, interpersonal relations, and processes, can help student teams to start the projects with the least cost of interpersonal relations and processes and high commitment. The results of the game-theoretic application on the three scenarios demonstrate that the team in the most effective category had determined the best strategies and had the highest total payoff for all for team members. The teams in the least effective and partially effective category could adopt the strategies of the most effective teams to improve their team effectiveness. In an educational setting, instructors can use the results of the study to help students develop and define effective strategies to maximize their learning gains [67,68].

As mentioned in [69,70], the student Scrum Master plays a positive enabling role in assisting the team to meet both quality and time project constraints. Our findings suggest that in general, a Scrum Master should be active to maximize their own payoff and the teams' overall payoff in project-based learning environments. On the other hand, other team members should be active in the most effective teams, but being passive in the least effective teams gives higher benefits to other team members at the increasing cost of interpersonal relations and processes. This could be due to higher costs of interpersonal relations and the processes which include conflict and miscommunication and yield lower benefit to team effectiveness [71]. Passive team members might improve their passiveness in teamwork by their instructors and Scrum Masters, assigning a reasonable workload and roles to them, allowing the class time to work on projects, and using peer evaluations as strategies [72,73]. Therefore, our results indicate that a game-theoretic model could explain the team members' passiveness in a team project. Based on that understanding, we might improve team members' activeness levels in terms of engagement and contribution to the team project.

## 7. Conclusions, Limitations and Future Work

We developed a game-theoretic model that explored the Scrum Master and other team members' interactions when they worked on a project as a team. During these interactions, the goal was for both the Scrum Master and other team members to optimize their overall payoff by maximizing their team effectiveness and minimizing the cost of interpersonal relations and processes. The results from the study conclude that overall team effectiveness is the result of the Scrum Master's effective leadership and the minimal cost of interpersonal relations and processes. The study also demonstrates the application of the game-theoretic model and details strategies adopted by each team with different effectiveness levels. The results of the study, therefore, are applicable to (a) educational settings in a project-based learning environment by following a cooperative learning approach, and (b) professional settings such as in the IT/software development industry by following the Scrum agile approach of software development. In both contexts, teams adopting the strategies of the most effective team could maximize their benefits.

The study provides a novel contribution to the literature addressing the interactions between the Scrum Master and team members through the lens of game theory. The study contributions can be extended to the realm of the industry that can enable professionals to use these strategies to maximize team effectiveness while planning and executing projects. Furthermore, the game-theoretic model developed in this study is applicable to educational contexts. It can be used to improve cooperative learning and collaboration within student teams.

The study was subject to the following limitations: (1) the study was able to demonstrate the application of the game-theoretic model based on data from only three teams, with one team selected from each effectiveness level; (2) only two strategies–active or passive–were considered as part of this study; (3) we have only considered the cost of the interpersonal relations and the processes. However, costs of time and effort were ignored due to complexity of the model; (4) the data scoring and analysis was conducted based entirely on the student team retrospectives; (5) the team retrospectives were collected from students enrolled in the Fall 2019 semester of the course; and (6) the student demographics were not available to be used as part of this study.

As a future work, we plan to extend our model to explore the interactions between the Scrum Master and team members with all the whole sample of twenty-three teams. Furthermore, we also intend to explore the teams with three or more strategies (such as partially or moderately active) using game-theoretic modeling. As another future work, we might include the cost of time and effort in addition to the cost of interpersonal relations and processes. The focus of this study was on cooperation among the team members. In the future, we aim to investigate the interactions among the other teams using non-cooperative game theory, especially if there is a competition between the teams. Focusing on conflict among the team members using non-cooperative game theory is another future direction we would like to take. Designing an intervention to educate students on cooperative game-theory principles and measuring the impact of the game theory intervention on students' collaboration would be another interesting direction for future work.

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