Team Effectiveness in Predicting Student Learning: An Analysis of First Year Engineering Students

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Abstract

This work-in-progress research paper addresses issues related to the measurement of team effectiveness. The study is motivated by recent changes in the ABET Criterion 3 accreditation guidelines, which state that students are mandated to demonstrate "an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives." In addition to ABET, the use of teams in engineering education has become a widespread pedagogical tool to facilitate the learning of technical content, as well as to prepare students for professional practice. Thus, having the ability to measure the effectiveness of such experiences is of both academic and industrial importance.

Even with the increased emphasis on the use of student teams in academia, research studies that rigorously attempt to assess team effectiveness are limited. Team effectiveness is an essential element of the overall collaborative experience, and the work presented herein will address the following research questions: 1) How do differences in perceptions of team effectiveness (measured by constructs of learning, interdependency, goal setting and potency) explain variability in individual learning? 2) How do differences in perceptions of team effectiveness (measured by constructs of learning, interdependency, goal setting and potency) predict variability in team performance?

The study involved two samples of over 1100 first-year engineering students in a large public institution enrolled in two consecutive First-Year engineering courses. Team sizes were nominally four students, with a limited number of teams of three students. Teams were formed with consideration of multiple criteria that included: sex, ethnicity, and educational background. Team effectiveness was measured in terms of a self-report, 24-item instrument, which has evidence of reliability and validity, that required students to indicate the degree to which their team worked together across a range of domains, including interdependency, learning, potency, and goal setting. Results to be presented include: psychometric analysis to support the combining of multiple datasets; Confirmatory Factor Analysis (CFA) that supports the factor structure of the team effectiveness measure; and predictive analysis to predict student team success measured by quiz scores, project grades, etc. using the self-reported team effectiveness as the independent measure.

Introduction

Since first including teamwork as a criterion for accreditation under the Engineering Criteria 2000, ABET revised the student outcomes criteria for accrediting engineering programs in the 2019-20 cycle to include more specific teaming requirements such as “an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives” [1] . They further elaborated on defining a team as a “[group] of more than one person working toward a common goal and should include individuals of diverse backgrounds, skills, or perspectives ” [2]. In addition, recent research pays more importance to training students in teamwork skills to be better prepared for professional working environments [3] [4] [5] [6]. Since the early 90s, more and more industries have required engineering graduates to be adept in non-technical skills including teamwork and interpersonal communication [7] [8] [9] [10]. In 2009, a poll for the Association of American Colleges and Universities (AACU) reported that 71% of companies laid emphasis on teamwork and collaboration skills in college graduates [11]. Thus, having the ability to measure the effectiveness of such experiences is of both academic and industrial importance.

Team-based learning has been defined and implemented in different ways. Swanson et. al. [12] define three levels of team-based instruction in classrooms: (1) casual small groups, (2) cooperative learning, and (3) team-based learning. While casual groups involve spontaneous activities with pairing of neighboring students in the classroom [13]; cooperative learning is the intentional infusion of group activities in classroom instruction [14] while team based learning(TBL) delves deeper and requires careful planning and changing of course structure to employ strengths of high performing teams [15]. Gallegos and Peeters [16] state that developing teamwork skills require adequate and intentional planning beyond forming students into groups.

Research indicates that the effects of TBL on student learning and self-efficacy of students during TBL implementations can be contradictory. While student performances, measured with grades, show higher or similar trends as traditional learning, perceptions and student attitudes of TBL are often negative or mixed, as reported in the meta-analysis of effect of TBL by Swanson et. al. [12] In addition, faculty are facing challenges in evaluating teamwork skills and assessing effective teams because of misconceptions about the aforementioned levels of teamwork and the lack of experience stemming from the history of traditional lecture classrooms. [17].

According to Campion, Medsker, and Higgs, team effectiveness is defined in terms of productivity, employee and customer satisfaction, and manager judgements [18]. It was inferred from their hypothesis that potency [19, p. 1003] and interdependency [20] were the most important attributes which contribute to an effective team in a real-world scenario. Study conducted by O'Leary-Kelly et. al. found evidence of goal setting having a significant effect on team performance [21]. While management education research has built instruments to create accountability of expectations amongst team members [22], literature on measuring team effectiveness in an engineering context were limited. Borrego et. al. used theory and findings from research in psychology and suggested applications in engineering, specifically facilitating teamwork in classrooms and minimizing negative team behaviors [23]. Arvold [24] built a teaching video module to train engineering students in developing skills of teamwork and communication. A comparison between globally and locally distributed teams by Ang revealed significant outperformance of local based teams [25]. Research shows that team effectiveness can be improved in communication and trust by informing students of their team members' personality types [26]. Previous work by Imbrie operationalized team effectiveness through interdependency, potency, goal setting and learning in the first-year of engineering college setting [27] [28] [29]. The literature on team effectiveness indicated limited work focusing on the relationship between perceptions of team functionality and their relation to performance in team activities. It was inferred from the literature that professionals who had positive perceptions of their production work teams were significantly more committed to the workplace than were those who held either neutral or negative perceptions [30] [31]. In addition, research was conducted to show evidence that gender-identities in a diverse team can impact perceptions of teams regardless of actual performances [32] [33]. Literature did not show evidence of such studies conducted in an engineering college setting. The current work attempts to study the relation between an effective team of students and performance in different elements of a course. Specifically, the research questions are:

1. *How do differences in perceptions of team effectiveness (measured by constructs of learning, interdependency, goal setting and potency) explain variability in individual learning?*

2. *How do differences in perceptions of team effectiveness (measured by constructs of learning, interdependency, goal setting and potency) predict variability in team performance?*

In the following sections, we discuss our methods to answer these questions, which includes a discussion on how these constructs are measured preceding the educational setting, participants and instrument selected for data analysis. We then elaborate on our data analysis followed by a discussion of results.

Methods

Individual learning and team performances were measured by different components of a first-year engineering course. Scores on computational tools sections of exams were used to measure individual performance and aggregate of project grades were selected for team performance respectively. Team effectiveness was measured using a scale developed by Imbrie et. al [27]. The scale measures team effectiveness in four constructs: Learning, Interdependency, Goal setting and Potency which are defined in the table. The instrument is further discussed later in this section after a description of the educational setting and participants.

Definitions:
Interdependence (Int) is broadly defined as "the extent to which the organization's task requires its members to work with one another" ([20], p. 156).
Goal setting (GlS) is a degree to which a clearly defined goal exists to which problem-solving activities are directed [34]
Team potency (Ptn) is general in emphasis, referring to 'the collective belief in a team that it can be effective' [35]
Team learning (Lrn) can be defined as learning done in teams where people teach each other how to learn to work effectively adapting to changes and thus leads to more effective work for the organization. [36]

Table 1: Constructs

Educational setting

The study was conducted in a large Midwestern R1 institution. In Fall 2018, first-year courses in fundamentals of engineering modelling were restructured to a course in fundamentals of engineering design thinking to implement team-based learning in an active-collaborative environment. The courses were developed as a two-semester long sequence with first-year student enrollment from all majors in engineering, engineering technology and some from engineering management and other colleges in the university. Classes were divided into 20-28 sections of about 60 students each. Each section had a teaching team of 4, including an instructor, a graduate teaching-assistant (GTA) and 3 undergraduate or Peer teaching assistants (PTAs). The instructional team comprised of 10-12 instructors, 10 GTAs and about 60 PTAs. The student to teacher ratio in the classroom was maintained at 1:12.

Fall semester curriculum covered topics of design process, teaming, engineering ethics, spatial visualization, data modelling, dimensional analysis, statistics, algorithmic thinking through flowchart, LabVIEW and Python. In the spring semester, topics of descriptive statistics and modelling, statics, electrical circuits, mass and energy balance, and algorithmic thinking through MATLAB and Visual Basic for Applications (VBA) were covered.

Students were grouped into teams of 3-4 members, formed at the beginning of each semester. Teams were required to work on 5 design and modelling projects through the course of 2 semesters. Project evaluations emphasized design process over project outcome, in line with Michael and Sweet's definition of TBL [37]. Teams were formed to maintain diversity in demography and programming knowledge measured from a self-reported instrument at the beginning of the semester.

All four computational tools (LabVIEW, Python, MATLAB and VBA) and several other topics were introduced in a flipped classroom set-up. Tutorial videos were developed as pre-class modules and students were expected to have been introduced to the concepts before class began. Classes started with a Readiness Assessment Tests (RATs), a short multiple-choice question to test the preparation of students from the pre-class modules. After a short discussion of concepts with the teaching team, students were given activities to be completed in teams followed by a test to Check for Understanding (CFUs). CFUs were conducted in-class either as a team assignment or individual test, randomly chosen by the instructor in each class. Students were also evaluated on weekly homework assignments and two course-wide exams in each semester. All assignments were graded using rubrics consistent for all sections.

Participants

This study was conducted in the 2018-19 academic year when the course was first introduced. All students enrolled in the course were assigned a 28-items instrument on team-effectiveness as part of a larger survey in a homework assignment at the end of each semester. Survey was administered as a regular homework assignment. Students were graded for the completeness of the survey and not by their responses[1]. Out of 1388 (80% Male, 20% Female, 78.24% White, 4.1% Black, 2.9% Hispanic, 9.6% Asian, 0.6% Native American, 4.4% Others) students at the end of the fall semester, 801 students (56.6%) answered the survey. In spring 2019, 648 (61.6%) out of 1020(79.8% Male, 20.2% Female, 80% White, 3% Black, 3.2% Hispanic, 4.9% Asian, 0.1 % Native American, 8.6% Others) students participated and completed the survey. Demographical data of respondents have been reported in Table 2.

[1] Homework was required but students were given the opportunity to opt out of the research. Students opting out of research were still graded. Only data from students who opted-in for the research were included in the study.

	Fall 2018	Spring 2019
Gender		
Male	614(76.6%)	497(76.7%)
Female	187(23.4%)	151(23.3%)
Race		
White	646(80.6%)	514(79.3%)
Black	23(2.9%)	17(2.6%)
Hispanic	19(2.4%)	22 (3.4%)
Asian	74(9.2%)	37(5.7%)
Native American	6(0.7%)	1(0.15%)
Others including not specified	33(4.1%)	57(8.8%

Table 2: Demographical Data of Respondents

Instrument

Team effectiveness was measured using a 28-items instrument with responses recorded on a 7-point Likert scale [38]. The instrument was initially developed by Imbrie et. al. and included 24-items to measure four factors namely *Interdependency, Learning, Potency,* and *Goal Setting* as components of team effectiveness [27]. The instrument was also developed using data from a large midwestern R1 university (albeit a different university) in the original study and showed evidence of high internal consistency reliability and validity. Given the similarity of our educational setting and sample, the instrument was considered to be appropriate for our data analysis. Two items, however, were added to the instrument to incorporate reversed-polarity. These items described experiences contrary to all other items. For example, while item7 read, "*Overall, I thought being on this team was a very negative experience*," item8 read, "*I feel a sense of accomplishment in my team's ability to work together*." While publishing the 26-items instruments, two items were incorrectly worded and duplicated leading to a 28-items instrument which has been presented in Appendix A. The duplicated items were later removed from analysis.

Data analysis

The abovementioned instrument was used to measure different elements of team effectiveness. Student learning was assessed using exam scores. Since, majority of learning in teams took place during the computational tools' sections of the course, individual questions on computational tools from the final exam in each semester were isolated and their total percentage calculated for each respondent. All five projects in the course were team assignments and majority of the work was done outside of class. This made them a good measure of team performance. All students in a team were given the same scores on projects with minor exceptions. Each team member's response to the items in the instrument was based on their own perception of the teaming experience and hence considered as an individual level of analysis. Owing to the separate measures of exam and project score in each semester, data collected from each semester were also considered separate and evaluated independently.

After thorough analysis of the variability in item responses, it was noticed that many responses had no variance between the items. Specifically, the validity items were compared with the other responses to see if they represented contradictory description of team experience. If such responses lay on the extreme sides of the Likert scale (all responses 0, 1, or 5, 6) they were considered as erroneous data and removed from analysis. This would mean that when a participant said they strongly agreed to having a "*sense of accomplishment* in *my team's ability to work together*" they could not have strongly agreed to "*Overall, I thought being on this team was a very negative experience.*" 41 and 55 responses were removed from the fall and spring data respectively using this argument.

Reliability analysis was conducted using Cronbach's coefficient alpha (a standard measure of internal consistency reliability) [39] and compared to fit criteria by Nunally [40].Confirmatory factor analysis (CFA) was performed to evaluate factor structure of the instrument for both sets of data separately. Fit indices like CFI, TLI (Tucker-Lewis Index), RMSEA (Root Mean Error of Approximations) and SRMR (standardized root mean square residual) were evaluated and compared to fit standards by Schermelleh-Engel et. al. [41]. Following this a linear regression model was fitted to the data to see relation between team effectiveness and performances.

Results and discussion

Cronbach's coefficient alpha for Fall dataset were: interdependency = 0.939; learning = 0.8758; goal setting = 0.8798; potency = 0.9356. Cronbach's coefficient alpha of scale was 0.9752. Similar internal consistency analysis of Spring data sets revealed a Cronbach's coefficient alpha for interdependency = 0.928; learning=0.8535; goal setting = 0.855; potency = 0.9204 and total = 0.969, showing evidence of high reliability of the instrument [40]. A four-factor model with uncorrelated factors was fitted using CFA which showed evidence of non-significant fit (Fall: CFI = 0.281, TLI = 0.2134, RMSEA = 1.3295 and SRMR = 0.5529; Spring: CFI = 0.2911, TLI = 0.2236, RMSEA = 1.1623, SRMR = 0.5280). These values correspond to an "unacceptable fit" as suggested by [41].

Indices in CFA for a 4-factor model with correlated factors were found to be within the acceptable fit limits (Fall: CFI =0.9973, TLI = 0.9969, RMSEA = 0.0828 and SRMR = 0.0450; Spring: CFI = 0.9962, TLI = 0.9957, RMSEA = 0.0856, SRMR = 0.0481). Multiple linear regression analysis of the data was conducted with the four factors as predictors and exam score as dependent variable for RQ1 and project performance for RQ2. While the assumption of normality of residuals was maintained on analysis, the high correlation between factors violated the multicollinearity assumption.

Data was analyzed for 1-factor fit model and showed similar results for near acceptable fit indices (Fall: CFI =0.997, TLI = 0.997, RMSEA = 0.0873 and SRMR = 0.04685; Spring: CFI = 0.9954, TLI = 0.9950, RMSEA = 0.0930, SRMR = 0.05107). The 1-factor model was representative of a measure of team effectiveness as a linear combination of all four factors. Simple linear regression results showed a non-significant model for RQ1 for fall data set (Fall: F = 1.947, df = 758, p-value: 0.1633) and significant model for RQ1 for spring data set (Spring: F =11.04, df = 591, p-value<0.001).

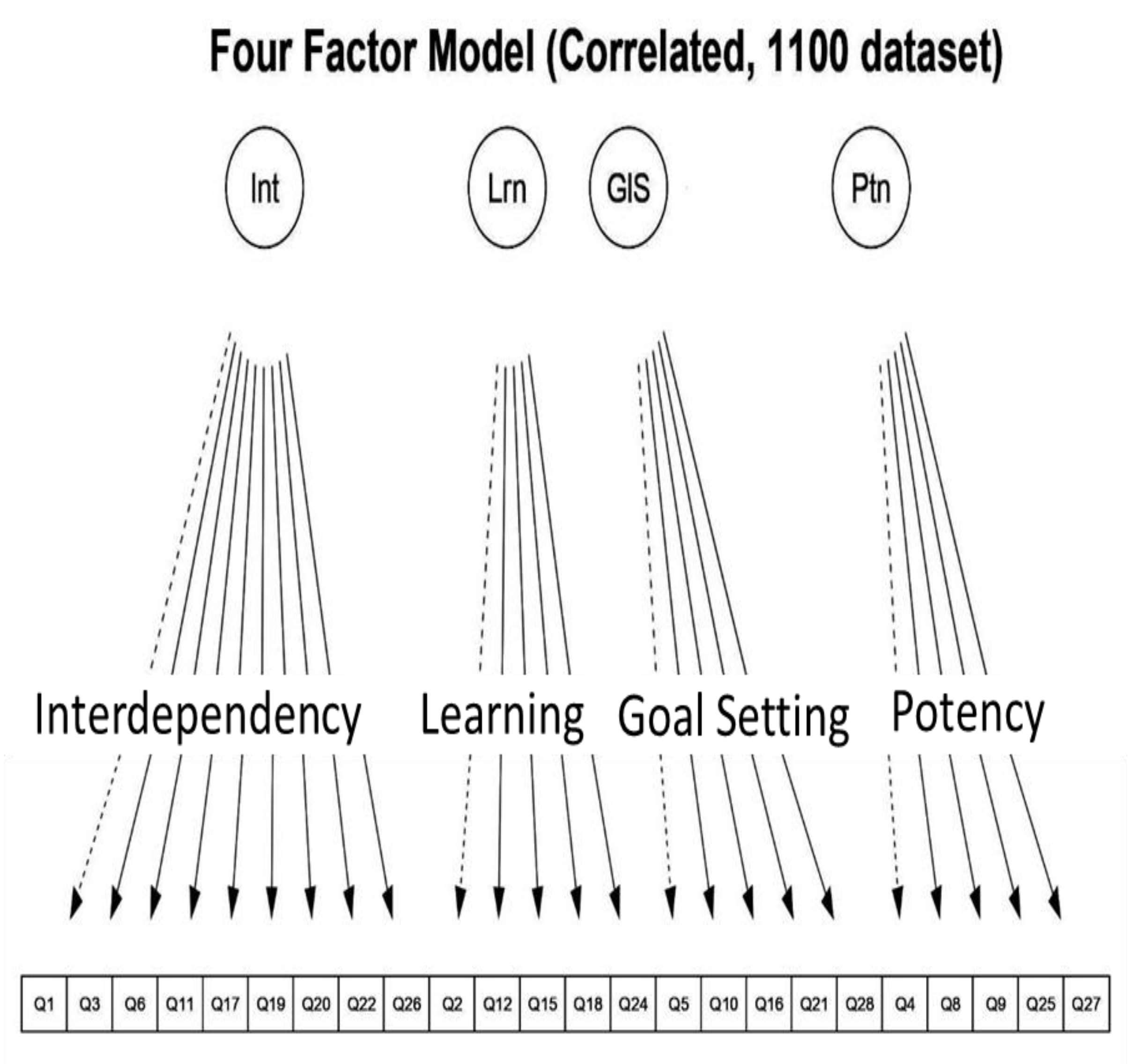

Figure 1: CFA of 4-Factor Model

Regression analysis for RQ2 revealed a significant model for Fall and Spring data set for 1-factor fit model (Fall: F = 17.46, df = 758, p-value < 0.001; Spring: F = 7.916, df = 591, p-value = 0.005). The coefficients of regression models were both significant for Fall (constant = 179.62 and coefficient for team effectiveness = 1.6377) and Spring (constant = 263.554 and coefficient for team effectiveness = 1.8792).

The above results show a significant positive relation between team effectiveness and team performance. With both data sets showing significant results, team effectiveness can predict team performances using a linear model. Contrary to expectation, Fall data set did not reveal a significant value for regression model to predict individual student learning measured by exam performance. A non-linear model can potentially provide a better fit and will be included in the later phases of the research.

Conclusion

This work-in-progress was able to show evidence of benefits in assessing team effectiveness to predict student performances in different aspects of the course in an engineering setting using CFA and linear regression analysis. A statistically significant linear model was presented to suggest relationship between team effectiveness and team performances. Further analysis is required to examine non-significant results between individual exam performance and team effectiveness. The work-in-progress helps in providing a measure for self-reported perceptions of student in teams and how those perceptions relate to student performances in various elements of a course. Studying such relations can be helpful in assessing team dynamics and their effects of student learning. With more emphasis on development of teaming skills in college graduates such assessments are both of industrial and academic importance. The current study aims to fill the gap in literature about team effectiveness in an engineering setting. This work-in-progress study will also be supported with longitudinal data of the second cohort of students enrolled in the course sequence. It can also be argued that opposing student perspectives of team functionality in the same team is a sign of dysfunctionality and the data will be studied for performances and perceptions grouped by teams.

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APPENDIX A

1. My team collaborated effectively to complete our assignments.
2. The solutions of my team to course assignments were better than what I would have done on my own.
3. My teammates displayed appropriate interpersonal skills when conflict arose.
4. My team was confident in its ability to overcome adversity (e.g., interpersonal conflict, assignments).
5. This team helped me accomplish my individual goals for this course.
6. My contributions to the team were appreciated by each team member.
7. Overall, I thought being on this team was a very negative experience. (reverse)
8. I feel a sense of accomplishment in my team's ability to work together.
9. This team gave me confidence in the ability of teamwork to solve problems.
10. My team used clear, long term goals to complete tasks.
11. I had confidence in each team member to contribute his/her fair share of what was required.
12. This team helped me understand the material presented in this course.
13. Deleted – incomplete question-
14. Our team did not function well as a team; we did not establish any process to hold one another accountable nor did I ever know what individuals were responsible for. (Reverse)
15. Working on this team made me realize that some things about myself (e.g., communication ability, leadership) that I was not aware of.
16. My team reflected upon its goals in order to plan for future work.
17. My team used a process/method (e.g., code of cooperation) to hold each member accountable.
18. This team enabled me to acquire the skills necessary to contribute to working on future teams.
19. Team members were prepared for team meetings.
20. Team members arrived on time to team meetings.
21. My team made use of incremental goals (i.e., we set short term goals) in order to complete course assignments on time.
22. At any particular time, I knew what each member of my team's role was
23. so, I knew what to expect from them - Deleted
24. This team enhanced my academic learning.
25. My team had the collective abilities (e.g., communication, interpersonal, technical) to accomplish course assignments.
26. An outside observer would have concluded our team had an effective process to complete our assignments.

27. I was confident that our team produced acceptable solutions to course assignments.
28. My input was used to set our team goals.