Enhancing Teamwork Skills in STEM Education: A Behavioral Theory-Based Approach

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Abstract

The ability to work in a team is one of the most important skills a college graduate can acquire from an educational institute. However, some students do not appropriately participate in course projects, making teamwork more challenging than it needs to be for others. As a result, many students fail to develop teamwork skills, and some become frustrated with course projects. This study adopted the Theory of Planned Behavior (TPB) to develop tools and a guide to enhance teamwork in course projects. Based on TPB, three interventions were developed: (1) a project description document including real-world examples of problems that can be solved with skills developed through the course project; (2) an accountability plan for the instructional team to provide social pressure to participate; and (3) a project management plan for the students to have a structure in the groups with well-defined roles. The interventions were adopted in two Fall 2023 courses (n = 39). Findings revealed significant improvements in student engagement, task completion, communication, role adoption, goal clarity, and conflict management post-intervention. These results confirm the efficacy of TPB-based interventions in enhancing teamwork skills among STEM students, underscoring the importance of behavioral theory in educational strategy development.

Introduction

Teamwork in STEM education holds paramount significance as it mirrors the collaborative nature of modern professional workplaces. STEM field involves solving complex problems that require multidisciplinary approaches with effective teamwork [1]. This necessity is reflected in the curriculum of STEM education, which frequently incorporates project work and group assignments to simulate real-world challenges. These educational strategies are not just about teaching technical skills; they are also about fostering an environment where students learn to collaborate effectively, share ideas, negotiate solutions, and manage group dynamics in a team.

The importance of teamwork in STEM education is underscored by Criteria 3 of the Accreditation Board for Engineering and Technology (ABET) [2]. This criterion mandates that student learning outcomes must include “an ability to function effectively as a member of a technical team.” This requirement is rooted in the understanding that the future workforce must be adept not only in technical knowledge but also in interpersonal and collaborative skills. By incorporating teamwork into their curricula, educational institutions help bridge the gap between academic learning and professional requirements.

Prior research has shown that effective teamwork is an important soft skill for building a set of skills that are essential in the modern world, including communication, problem-solving,

adaptability, and leadership [3], [4]. Teamwork in STEM education teaches students how to articulate their ideas clearly, listen to others, and collaborate to refine concepts, which are essential skills in any professional environment [5]. Additionally, working in a team allows students to address more complex problems through task division and knowledge sharing, leading to more sophisticated and comprehensive problem-solving strategies [6]. Teamwork also provides opportunities for students to take on leadership roles, whether in managing a project, leading a discussion, or coordinating tasks. These skills enhance students' abilities to contribute effectively to their future careers and to society at large.

Literature Review

In the past decade, there has been significant research aimed at assessing the teamwork skills of STEM students through the modification of course materials, the introduction of new techniques, and the implementation of technology-driven projects, as well as replacing traditional individual assignments with cross-disciplinary projects [7], [8]. A study on the impact of an NSF-supported STEM scholarship program revealed that a one-credit course focusing on teamwork significantly improved students' presentation skills and interpersonal confidence [9]. However, the project work was deemed too time-consuming for a one-hour credit course, and the issue of uneven work distribution among team members remained unresolved. In another study, an assessment framework was developed to evaluate the teamwork skills of students in the STEM field [10]. Nevertheless, there were no structured guidelines for improving teamwork skills among the students. Again, a tool for measuring university students' contributions to group work in educational settings named the Group Work Contribution Scale (GWCS) was developed by a study in which it focused on four key factors: effort, initiative, responsibility, and backing-up behavior [11]. Moreover, the CATME.org web-based tools support colleges in assessing and enhancing students' team skills, which are crucial for AACSB accreditation and valued by employers, by facilitating data collection and analysis for demonstrating achievement in teamwork-related learning goals [12].

Many graduate schools have developed their own methodologies to enhance and assess teamwork skills among students. Cornell University has developed a rubric system focusing on contributions, attitudes, cooperation with others, focus, commitment, and team role fulfillment for evaluating teamwork, incorporating peer evaluations in the assessment process [13]. The University of Alberta has introduced a 360-degree evaluation method where a student is evaluated by the instructor, by his/her teammates, and through self-assessment [14]. Similarly, the University of Waterloo uses peer-review assessments alongside instructors’ evaluations for teamwork assessment [15]. Carnegie Mellon University has also implemented an assessment tool that focuses on group participation, responsibility, adaptability, and general team skills [16]. However, most of these assessment tools and frameworks focus more on assessment than on the development of teamwork skills in STEM students. Therefore, it is essential to develop guidelines and frameworks based on behavioral theory to enhance the teamwork skills of STEM students, as the development of these skills involves subjective factors and behavioral psychology.

While in today's industrial workplaces, teamwork and collaboration have become major components of success, graduate schools are emphasizing more on teamwork skill evaluation rather than the development of this skill among students. However, it is imperative to develop teamwork skills among the students with some structured methodologies throughout the coursework. To fulfill this responsibility, educational institutes must provide tools and training to support instructors in developing useful and well-designed course projects, motivating students to participate, and keeping them accountable. Research suggests that instructors struggle to ensure student participation in course projects due to a lack of motivation from some students [17]. Some students choose not to or cannot appropriately participate because they do not see a direct application of the project experience in their career, of a lack of structure in their group, or an absence of effort from the instructional team to ensure participation [18]. Instructors also do not have the training to develop a well-defined and well-organized project document and do not have the tools or manpower to maintain proper teamwork. Students who are willing to contribute to their group projects experience a higher-than-usual workload, leading to a bad impression of teamwork and collaboration. Anecdotally, the investigators have seen students feel de-motivated to enroll in project-based courses. As a result, many students fail to gain teamwork skills and do not understand how to collaborate with others, lowering the quality of education they receive from an educational institute. Therefore, this paper aims to develop a guide and tools, based on a behavioral theory, to improve student participation in teams. There are several behavioral theories that explain why humans do the things they choose to do. One highly adopted theory is the Theory of Planned Behavior (TPB) [19]. The current study aims to develop the guidelines and framework for enhancing effective teamwork skills among STEM students by investigating the following research question: Can student participation be improved with the interventions based on TPB?

This question aims to empirically test the effectiveness of specific interventions based on the TPB in enhancing student participation in team projects. The answer to this question would provide empirical evidence supporting the development of tools to ensure effective teamwork in course projects. The implication of answering this question lies in its potential to validate the TPB-based interventions. If proven effective, these strategies could be developed into practical tools and guidelines, fundamentally changing how teamwork skills are fostered in educational settings. This would not only improve student engagement but also ensure that graduates possess crucial collaborative skills, meeting the demands of modern workplaces.

Method

Data Collection

The investigators implemented the three interventions in two engineering courses of Industrial Engineering in Fall 2023 at a university in the USA. Three interventions were developed by the investigators that were applied to 39 students to improve their teamwork skills in the course project. Table 1 shows the demographic information of the students. A questionnaire was prepared in such a way so that it can be used for both pre-implementation and post-implementation of the interventions. The questionnaire has been given in Appendix A.

Table 1. Demographic information of the students

Demographic variables	Distribution (N = 39)
Age	18 - 25 years old = 22 26 - 35 years old = 14 36 - 45 years old = 02 Older than 45 years = 01
Gender	Male = 34 Female = 05
Education	Bachelor of Science program = 07 Master of Science program = 25 Doctor of Philosophy program = 07
No. of projects	0 - 5 projects = 17 6 – 10 projects = 16 11 – 15 projects = 04 More than 15 projects = 02

Theoretical Framework

According to TPB, human behavior (intention to perform a behavior and the actual behavior) can be explained by attitude toward the behavior ("favorable or unfavorable evaluation," p. 188 [20]), subjective norm ("perceived social pressure," p. 188 [19]), and perceived behavioral control ("ease or difficulty to perform the behavior," p. 188 [19]). Given the success of adopting TPB to explain a huge variety of human behaviors, this study proposes to apply TPB to improve student participation in the course project teams. The working hypothesis is that by (i) effectively conveying the importance of gaining teamwork skills, (ii) showing the direct application of a given project in students' careers, (iii) providing social pressure with regular meetings with the instructional team, and with peer review, and (iv) making participation easier by asking the students to create structure in their group with well-defined roles would improve attitude, social norm, and perceived behavioral control and hence would improve student participation in teams.

The first intervention was to show the application of a given project. This intervention required instructors to select a project topic that was useful to explain the application of the topic with great examples to the students. The investigators developed project documents with examples of real-world situations where the students were able to apply their knowledge gained by participating in the given project. Intervention 2 was to develop an accountability plan. Some regular Bi-weekly meetings with the instructional team were held to discuss project progress. After every two bi-weekly meetings (once per month), students evaluated their personal and group performance. The final intervention was to make it easy to participate. To implement this intervention, each team was required to conduct a kick-off meeting with "ice-breaking" sessions. In that meeting, they also came up with plans (for communication, conflict management, etc.) for project management and specify roles (rotational) for themselves.

Analysis Technique

A baseline data was collected at the beginning of the semester to assess students' past participation in teams and their perception of teamwork. After implementing the interventions, a

final data collection was done to measure student participation and their perception of teamwork. The effect of the interventions (Research Question #1) was measured using the improvement (or deterioration, calculated by subtracting the baseline score from the final score) in student participation and their perception of teamwork. Student teamwork was measured using the Team-Q survey [21] in all four stages (baseline, two intermediates, and the final) with some modifications. The investigators collected data from the instructional teams to assess the potential impact on their workload, overall satisfaction, and course evaluation. The responses from the instructional team provided information about the challenges to implementing the interventions and the need for support for the instructors. Pareto analysis has been performed to rank the causes of ineffective teamwork among the STEM students. The students' responses from the Q survey were analyzed by simply taking the average of the scores.

Results

This section describes the findings from the survey conducted before and after the implementation of interventions based on TPB. Figure 1 shows the Pareto analysis of the causes of ineffective teamwork in STEM projects. The finding has revealed that "Equitable contribution" and "Lack of communication" are the topmost reasons for ineffective group work in STEM education. In many cases, students rely on other team members to complete the tasks of STEM projects. Again, sometimes there is no formal communication system among the team members. "Improper work distribution" and "Lack of motivation" are the next two most significant reasons identified in this study. The other contributing factors for ineffective group works in STEM education are "Lack of accountability", "Lack of clarity of goals", "Lack of knowledge", "Weak leadership", "Conflict among members" and "Lack of responsibility".

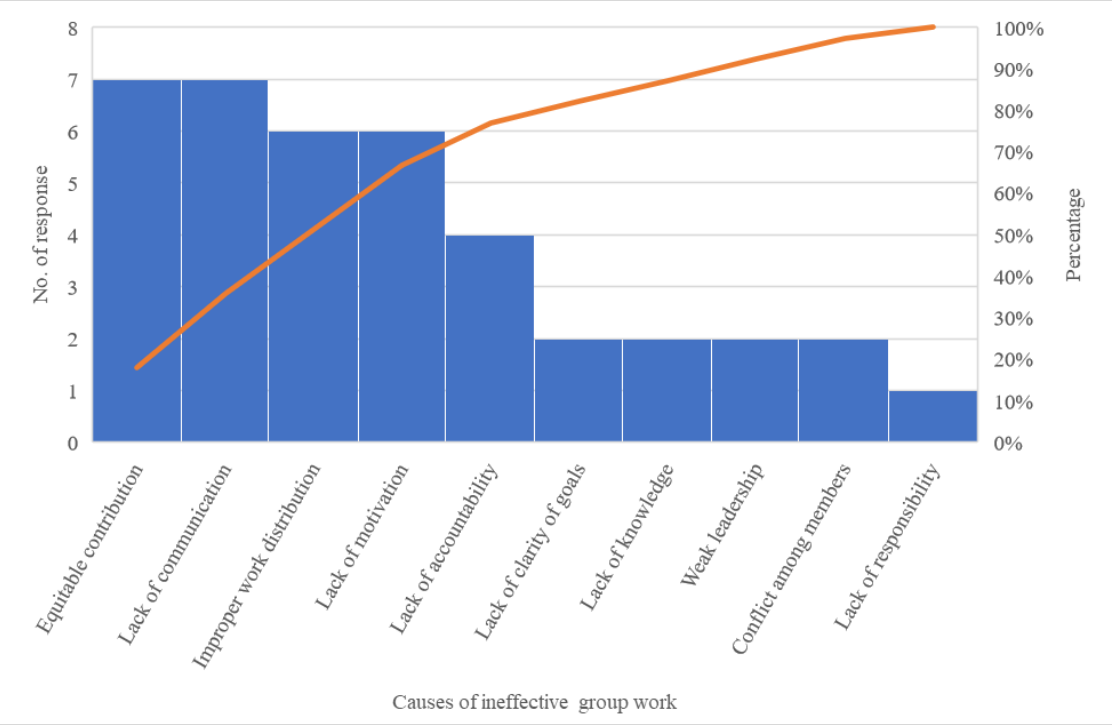

Figure 1. Pareto chart for the causes of ineffective teamwork in STEM projects

Feedback was collected using a structured survey (Team-Q survey [21]) that assessed various components of teamwork, including contribution to team projects, facilitating contributions of others, planning and management, fostering a team climate, and managing potential conflict. Students rated their experiences on a Likert scale, with scores ranging from 1 (strongly disagree) to 5 (strongly agree). The average scores before and after the interventions were calculated to evaluate the effectiveness of the interventions. Table 2 shows the comparison of students' feedback about group work before and after the intervention.

Table 2. Comparison of students' feedback about group work before and after the intervention

Components/Survey Items	Average score (Before intervention)	Average score (After intervention)
A. Contributes to Team Project		
1. Participates actively and accepts a fair share of the group work	3.4	4.1
2. Works skillfully on assigned tasks and completes them on time	3.6	4.1
3. Gives timely, constructive feedback to team members, in the appropriate format	3.3	4.1
B. Facilitates Contributions of Others		
4. Communicates actively and constructively	3.5	4.1
5. Encourages all perspectives be considered and acknowledges contributions of others	3.7	4.3
6. Constructively builds on contributions of others and integrates own work with work of others	3.4	4.1
C. Planning and Management		
7. Takes on an appropriate role in the group (e.g. leader, note taker)	3.2	4.1
8. Clarifies goals and plans the project	3.4	4.3
9. Reports to the team on progress	3.4	4.1
D. Fosters a Team Climate		
10. Ensures consistency between words, tone, facial expression, and body language	3.5	4.2
11. Expresses positivity and optimism about team members and the project	3.6	4.3
E. Manages Potential Conflict		
12. Displays appropriate assertiveness: neither dominating, submissive, nor passive-aggressive	3.4	3.9
13. Contributes appropriately to healthy debate	3.4	3.9
14. Responds to and manages direct/indirect conflict constructively and effectively	3.3	4.2

Students' active participation and equitable sharing of the workload saw a notable increase in average scores from 3.4 (before the intervention) to 4.1 (after the intervention). The skillful completion of tasks on time improved from an average of 3.6 to 4.1, and the provision of timely,

constructive feedback to team members rose from 3.3 to 4.1. These improvements indicate a substantial enhancement in student engagement and contribution quality to team projects. The scores for active and constructive communication increased from an average of 3.5 to 4.1. Encouragement for considering all perspectives and acknowledging the contributions of others improved significantly, with average scores rising from 3.7 to 4.3. Additionally, the constructive integration of individual work with that of others saw an increase from 3.4 to 4.1. These results suggest a more inclusive and collaborative team environment post-intervention. The ability of students to take on appropriate roles within the group improved, as reflected by the increase in average scores from 3.2 to 4.1. The clarity of goals and project planning capabilities also saw significant enhancement, with scores rising from 3.4 to 4.3. Regular reporting on team progress improved from 3.4 to 4.1, indicating more structured and accountable teamwork. There was a noticeable improvement in ensuring consistency between verbal and non-verbal communication, with average scores increasing from 3.5 to 4.2. The expression of positivity and optimism about team members and the project improved from 3.6 to 4.3, suggesting a more supportive and motivating team climate. The display of appropriate assertiveness saw a modest increase in average scores from 3.4 to 3.9. The contribution to healthy debate and effective conflict management also improved, with both components rising to an average score of 3.9 from 3.4, indicating a balanced approach to resolving conflicts within teams.

These numerical improvements across the board not only demonstrate the effectiveness of the TPB-based interventions in enhancing teamwork skills among STEM students but also highlight the potential for structured, theory-based approaches to foster a more engaging, inclusive, and collaborative educational experience.

Discussion

By developing and applying the TPB-based interventions, the current study aimed to address three key aspects influencing student participation: attitudes towards teamwork, perceived social norms, and perceived behavioral control. The TPB has been chosen as the theoretical foundation due to its well-documented effectiveness in predicting and understanding behavior change across various domains, including education. Additionally, the survey instrument was designed not only to identify deficiencies but also to highlight areas for growth and development in student teamwork capabilities. By framing questions to capture both current competencies and potential areas of improvement, the current approach has fostered a constructive view, encouraging students to recognize and build upon their existing teamwork skills. The findings demonstrated significant improvements in student engagement and the quality of teamwork, providing valuable insights into the effectiveness of TPB-based interventions in STEM educational settings. The interventions led to notable improvements across several dimensions of teamwork, including active participation, equitable workload sharing, timely task completion, and constructive communication. These results are indicative of a positive shift in students' attitudes towards teamwork, an increase in perceived social pressure to contribute meaningfully to team projects, and an enhanced sense of behavioral control over their ability to participate effectively. Such improvements are critical, given the importance of teamwork and collaboration skills in both academic and professional contexts. From the Pareto analysis shown in Figure 1, the key reasons

of ineffective teamwork in educational settings have been identified, such as uneven work distribution, lack of motivation, and communication barriers. This was a crucial step before designing the intervention. Previous studies also found similar contributing factors for ineffective teamwork [22]. Considering the challenges, this study has designed the interventions based on the TPB. The comparative analysis represented in Table 1 clearly shows that the application of these interventions has significantly affected the various aspects of effective teamwork skills. The contribution of the students as members has been improved through these interventions. Moreover, according to the feedback of students, project planning and management skills of the students were improved after the interventions. Similarly, the feedback of students implies that the application of other interventions was successful. The current study's findings suggest that by addressing the underlying behavioral intentions and perceptions, it is possible to significantly improve teamwork dynamics.

The results underscore the importance of creating an educational environment that not only values technical skills but also places a premium on developing soft skills such as teamwork, communication, and leadership. Given the critical role these skills play in the professional success of graduates, the positive outcomes of the interventions offer a valuable blueprint for educational institutions aiming to bridge the gap between academic training and the demands of the modern workplace. The main conclusions of this study, which showed that TPB-based interventions significantly improved STEM students' teamwork abilities, correlate strongly with earlier research on the growth of soft skills in educational contexts [23]. The practical implications of these findings are substantial for educators and curriculum designers. By implementing targeted interventions that resonate with students' behavioral intentions and perceptions, educational institutions can create more engaging and productive learning environments. This approach not only enhances the immediate learning experience but also equips students with essential skills for their future careers. Moreover, the study's results underscore the importance of integrating soft skills development into STEM curricula, aligning educational practices with the demands of the modern workforce.

Conclusion

The study concludes that TPB-based interventions can effectively enhance student participation in team projects within STEM education. These interventions offer a promising avenue for educators seeking to improve teamwork and collaboration among students. However, the study also acknowledges limitations, such as the potential variability in intervention effectiveness based on individual student differences and the broader applicability across different STEM disciplines.

Future research should explore the long-term impacts of these interventions on students' teamwork skills and their transition to professional environments. Additionally, further studies could investigate the scalability of the interventions and their adaptability to diverse educational contexts and student populations. The effectiveness of the interventions can be evaluated by comparing the teamwork skills of the students who have the interventions and those who do not have the interventions. By continuing to refine and expand upon the current study's interventions,

educators can better prepare students for the collaborative challenges of the 21st-century workplace.

In summary, this study contributes to the ongoing dialogue on enhancing teamwork in STEM education by offering evidence-based interventions grounded in behavioral theory. Its findings not only validate the application of the TPB in educational settings but also provide practical strategies for fostering a more collaborative and engaging learning experience for students.

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Appendix A: Survey Questions

Demographic Questions:

1. What age group do you belong to?
    - 18 - 25 years old
    - 26 - 35 years old
    - 36 - 45 years old
    - Older than 45 years

2. Which of the following best describes your gender?
    - Male
    - Female
    - Others

3. What is your current education level?
    - Student in a Bachelor of Science program
    - Student in a Master of Science program
    - Student in a Doctor of Philosophy program
    - Others

4. Before this semester, how many course group projects (including capstone projects) did you have participated in?
    - 0 - 5 projects
    - 6 - 10 projects
    - 11 - 15 projects
    - More than 15 projects

5. Based on your previous experience in course group projects, overall, how satisfied are you with your group members' participation?
    - Very Unsatisfied
    - Unsatisfied
    - Neutral
    - Satisfied
    - Very Satisfied

6. Based on your previous experience, tell us why [sometimes] it is difficult to ensure appropriate contribution from all team members.

Teamwork Related Questions

This part of the survey utilizes the Team-Q survey to assess team participation. Some modifications are made to fit the questionnaire to the context of data analysis.

In your experience, how often does your peer demonstrate the following?

Components/Survey Items	**1** - Never	**2** - Sometimes	**3** - Usually	**4** - Regularly	**5** - Always
Contributes to Team Project					
7. Participates actively and accepts a fair share of the group work					
8. Works skillfully on assigned tasks and completes them on time					
9. Gives timely, constructive feedback to team members, in the appropriate format					
Facilitates Contributions of Others					
10. Communicates actively and constructively					
11. Encourages all perspectives be considered and acknowledges contributions of others					
12. Constructively builds on contributions of others and integrates own work with work of others					
Planning and Management					
13. Takes on an appropriate role in the group (e.g. leader, note taker)					
14. Clarifies goals and plans the project					
15. Reports to the team on progress					
Fosters a Team Climate					
16. Ensures consistency between words, tone, facial expression, and body language					
17. Expresses positivity and optimism about team members and the project					
Manages Potential Conflict					
18. Displays appropriate assertiveness: neither dominating, submissive, nor passive-aggressive					
19. Contributes appropriately to healthy debate					
20. Responds to and manages direct/indirect conflict constructively and effectively					