NUMBO: Exploring the Collaborative Skills and Engagement of Grade 9 Students during a Mathematics Performance Task

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Abstract: This study explored the effectiveness of NUMBO, a modified bingo game, in fostering collaborative skills and engagement among Grade 9 students during a mathematics performance task. Conducted at a laboratory school affiliated with a Teacher Education Institution (TEI) in Manila, the intervention was grounded in Constructivist Learning Theory and Experiential Learning Theory. The qualitative case study employed non-participant observation to examine how students interacted, collaborated, and solved problems while participating in the game-based activity. Data were gathered using guided observation protocols and analyzed thematically with the aid of artificial intelligence tools. Findings revealed that effective groups consistently demonstrated structured role assignments, continuous communication, and peer support. These groups remained engaged even during complex tasks such as completing the square or applying the quadratic formula. In contrast, ineffective groups exhibited declining motivation, minimal coordination, and fragmented efforts due to a lack of strategy, unclear roles, and inconsistent participation. The intervention also revealed that a healthy sense of competition contributed positively to student engagement when it was aligned with group cooperation. The study underscores the value of structured game-based learning in enhancing collaborative dynamics and sustaining student motivation in mathematics education. NUMBO proved effective in transforming routine mathematical tasks into interactive, engaging, and socially enriching experiences. The results suggest that when supported by strategic design and intentional facilitation, game-based interventions can promote active participation, teamwork, and deeper conceptual understanding. Recommendations include integrating such interventions in regular instruction and conducting further studies on their long-term impact on academic performance and peer collaboration.

Key Words: Mathematics Education; Game-based Learning; Collaborative Learning; Student Engagement

1. INTRODUCTION

1.1 Background

According to a 2024 report by *Business World*, only 16% of Filipino students achieved at least Level 2 proficiency in mathematics during the fifth cycle of the 2022 Programme for International Student Assessment (PISA), a figure significantly lower than the 69% average among countries participating in the Organisation for Economic Cooperation and Development (OECD). This disparity is attributed to various factors affecting mathematics performance, including heightened levels of mathematical anxiety and the lack of a strong foundation in essential mathematical skills.

These challenges extend beyond student performance and encompass systemic issues within the educational landscape. Teachers often lack adequate support and resources, face inconsistencies in curriculum implementation and assessment, and are burdened with administrative tasks that detract from instructional time. Collectively, these factors contribute to what Bautista and Aranas (2023)

describe as a "learning crisis," one that reflects not only weaknesses within the education system but also broader societal inequities. In response, Callaman and Itaas (2020) conducted a study in Mindanao which, despite reporting modest overall effect sizes in mathematics achievement, highlighted mathematical skills, attitude, and self-efficacy as significant predictors of student success. Their study also revealed performance gaps between public and private schools, underscoring the need for periodic curriculum review and the adoption of diverse instructional strategies that foster interest and positive attitudes toward mathematics.

Targeted interventions focused on fundamental operations may offer a crucial path toward addressing these concerns. For instance, Adonis (2020) introduced Contextualized Strategic Intervention Materials (CSIMs) designed for Grade 9 learners, which aligned instruction with local contexts and significantly improved student understanding, engagement, and comprehension. Similarly, Taracina (2024) evaluated the Math-Collab intervention, a differentiated strategy based on multiple intelligences. Students in the experimental group demonstrated notable gains in post-test performance (79.75%) compared to the control group (64.30%), suggesting that collaborative group work and positive reinforcement can enhance both achievement and student disposition toward mathematics.

Further support for collaborative and mindset-based approaches comes from Boaler et al. (2022), who implemented the "mathematical mindset approach" to foster productive mathematical habits. Their study found that students improved in both problem-solving and collaboration, with 35% of student pairs showing measurable gains in teamwork. These findings reinforce the potential of structured, collaborative, and contextually relevant interventions in addressing the cognitive and affective challenges faced by Grade 9 students.

Given this context, the present study aims to examine how the proposed intervention—NUMBO—supports student engagement and fosters collaboration during a mathematics performance task. Specifically, it seeks to explore how game-based learning environments can facilitate peer interaction and sustained participation within the classroom setting.

1.2. Framework

This study is grounded in Constructivist Learning Theory, which emphasizes that learners actively construct knowledge through personal experiences and social interaction (Chand, 2023). In this perspective, learning in mathematics goes beyond memorizing procedures and formulas; it involves engaging students in meaningful problem-solving tasks that connect abstract concepts with real-world contexts. A constructivist mathematics classroom encourages exploration, collaboration, and discussion, enabling students to internalize mathematical ideas more deeply.

In particular, the intervention employed in this study—NUMBO, a modified bingo game—embodies the principles of constructivism by situating students in a collaborative and competitive learning environment. Figure 1 shows sample NUMBO card. During gameplay, learners actively participate in solving mathematical problems, communicate with peers, and receive immediate feedback, thereby facilitating deeper conceptual understanding.

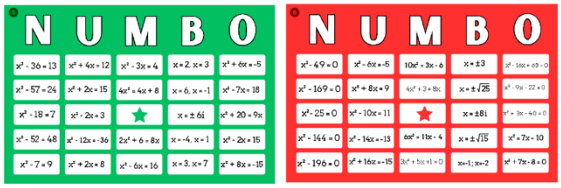

Fig 1. Sample NUMBO Cards

The use of game-based learning as a pedagogical strategy has been widely supported in literature. Studies have shown that integrating educational content into games enhances student motivation, engagement, and peer interaction (Plass et al., 2015; Falciani, 2024). For instance, the use of board and card games such as Intego, a modified Uno for practicing integer operations (Chong et al., 2022), and the ROPE and RACE Snakes and Ladders-based intervention (Del Rosario, 2023), has resulted in improved skills in operations and increased classroom participation. These interventions are effective because they present tasks in playful formats that lower math anxiety while fostering resilience and persistence (Ayyasy & Asrul, 2024; Molina & Ibañez, 2024).

Moreover, studies on structured classroom interventions—such as the Strategic Intervention Material (SIM) (Arpilleda, 2021) and the FRAME model (Ebajan & Tamban, 2024)—highlight the importance of guided, differentiated activities and regular feedback in supporting student growth. NUMBO shares similar characteristics by embedding structure into gameplay: students must collaborate, assign roles, and validate answers collectively. The presence of strategic competition further amplifies engagement and encourages peer support, which are foundational elements of both constructivist and social learning theories.

As shown in the intervention's conceptual framework (Figure 2), NUMBO is treated as the independent variable, while the dependent variables include student engagement and collaborative skills. Engagement is defined by indicators such as excitement, resilience, and persistence during the activity, while collaboration is measured by the presence of structured role assignment, continuous peer communication, and mutual support. Observational data captured group dynamics and student behavior throughout the NUMBO intervention, with effective groups demonstrating high levels of coordination and enthusiasm, and ineffective groups showing fragmentation, low morale, and passive participation.

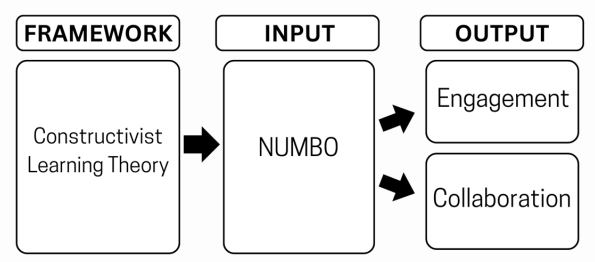

Fig. 2. Framework of the study

This framework integrates both theoretical and empirical foundations, providing a structured lens to examine how game-based interventions can enhance socio-emotional and cognitive aspects of learning. It assumes that when properly facilitated, tools like NUMBO can promote meaningful interaction, active learning, and improved mathematical engagement among students working in groups.

2. METHODOLOGY

2.1. Research Design

This study employed a qualitative case study observational design to explore the collaborative skills and engagement of Grade 9 students during a mathematics performance task involving NUMBO, a modified Bingo game. A case study design allows for in-depth exploration of contemporary phenomena within real-life contexts and is particularly effective in addressing "how" and "why" questions (Baxter & Jack, 2008). This methodology is well-suited to examine the natural classroom dynamics, including students' communication patterns, collaborative strategies, and behavioral engagement during learning tasks.

The study utilized non-participant observation, allowing the researchers to capture authentic student interactions without influencing the classroom environment. This approach is particularly effective in educational settings, where social behaviors, group processes, and problem-solving strategies unfold in real-time (Creswell & Poth, 2017). The findings were intended to inform the integration of game-based interventions to enhance collaborative and engaging mathematics instruction.

2.2. Sample and Locale

The study was conducted in a Grade 9 mathematics class at a laboratory school affiliated with a Teacher Education Institution (TEI) in Manila. This setting—known for its collaborative learning culture and openness to educational interventions—provided an ideal environment for implementing NUMBO. All Grade 9 students, aged 13 to 15, were included in the study, ensuring diverse representation in terms of socioeconomic backgrounds.

As a laboratory school, students and parents had pre-consented to participate in research during enrollment. Nonetheless, researchers secured administrative approval and issued age-appropriate assent forms. Adhering to ethical standards and the Data Privacy Act of 2012 (RA 10173), all data were anonymized and handled with strict confidentiality.

No specific sampling method was applied. Instead, the entire Grade 9 population was included, eliminating the need for randomization or stratification while maximizing ecological validity.

2.3. Data Collection

Prior to data collection, a formal request letter was submitted to the principal and academic dean. Once approved, the intervention was conducted during the first quarter of Academic Year 2024–2025. Data collection lasted approximately one hour and began with a brief orientation and demonstration of the NUMBO game. Students were grouped and guided by assigned student teachers, who verified answers. Teacher-assistants, trained in observation protocols, were tasked with documenting collaborative and engagement behaviors across four gameplay rounds. Figure 3 shows the data collection set-up.

Fig. 3. Data Collection Set-up

The researchers followed strict ethical guidelines throughout the process. Upon completion, findings were shared with students and parents through digital copies of the final report. The study was also submitted to the host institution as part of Field Studies 1 and 2 requirements.

To capture the complexity of classroom interactions, the study relied on systematic observational techniques. Observation protocols focused on how students interacted, communicated, and supported one another. This approach echoes those used in similar research on mathematics collaboration (e.g., Bature & Atweh, 2019; Swaran Singh et al., 2017), which emphasized the value of live observations and triangulated data to assess group learning behavior.

2.4. Data Analysis

The study employed Thematic Analysis, following the process outlined by Braun and Clarke (2012). This method enables researchers to systematically identify and interpret patterns across qualitative datasets, particularly those that capture participants' behaviors and experiences.

To enhance both analytical efficiency and objectivity, the researchers employed ChatGPT OpenAI o3, an artificial intelligence tool, to assist in the initial generation of themes. Observation data were uploaded into the tool, along with the following prompt:

"Perform thematic analysis to describe the engagement and collaboration of students using attached observed group strategy and member characteristics. Divide the themes into four: Engagement of Effective Groups, Engagement of Ineffective Groups, Collaboration of Effective Groups, and Collaboration of Ineffective Groups."

The AI-generated output underwent a thorough review process, wherein all non-factual and irrelevant results were systematically identified and excluded to ensure the accuracy and relevance of the final analysis. The finalized themes captured recurring behavioral patterns, communication styles, and collaboration strategies, allowing for rich interpretations grounded in both human and machine-assisted coding. This dual approach ensured the reliability, validity, and efficiency of the qualitative analysis process.

3. RESULTS AND DISCUSSION

The results of the study were categorized into four thematic areas based on classroom observations: (1) Engagement of Effective Groups, (2) Engagement of Ineffective Groups, (3) Collaboration of Effective Groups, and (4) Collaboration of Ineffective Groups. These themes emerged from direct classroom observations during the NUMBO game intervention, guided by predefined indicators of student engagement and collaborative behavior.

3.1. Engagement during NUMBO

Student engagement during the NUMBO activity varied notably across groups. The effective groups—particularly Groups 4 and 6—consistently demonstrated high levels of enthusiasm, focus, and energy throughout the game. These students actively discussed strategies, remained persistent in solving complex problems, and drew motivation from the healthy sense of competition embedded in the activity. Their sustained involvement was further

characterized by mutual encouragement and celebration of group progress. The emerging themes that capture this dynamic are summarized in Table 1.

Table 1. Themes on Engagement of Effective Groups

Themes	Description	Sample Observations
Excitement	Students approached each problem with enthusiasm and energy, creating an environment where their intrinsic motivation kept them focused and driven to tackle tasks consistently.	S1.1, S4.5, S4.7, S4.9, S6.12: "Shows excitement during the game, especially for every next round."
Resilience and Persistence	The group members showed unwavering commitment, staying engaged and persevering through challenging topics like completing the square and applying the quadratic formula, which required deep understanding and sustained focus.	S1.1, S1.2, S6.10, S6.11, S6.12, S4.5, S4.6, S4.7: "Doesn't give up until finding out the answer."
Competitive Drive	A healthy sense of competition motivates students to act quickly and stay aligned with their peers, fostering a supportive environment where the focus is on achieving shared success rather than individual superiority.	S1.1, S1.2, S1.3, S4.5, S4.6, S4.8, S6.10, S6.11, S6.12: "Shows competitiveness by answering faster and encouraging groupmates to answer as well."

In contrast, ineffective groups—specifically Groups 2, 3, and 5—exhibited a steady decline in engagement as the task became increasingly difficult. Although they initially participated with enthusiasm, these groups struggled to maintain focus and momentum. Students often worked in isolation, expressed visible frustration, and gradually disengaged when faced with more challenging mathematical problems. These patterns of declining participation and lack of resilience are captured in Table 2.

Table 2. Themes on Engagement of Ineffective Groups

Themes	Description	Sample Observations
Decreasing Excitement	Initial enthusiasm faded, especially as students faced difficulties with more complex problems.	S5.25, S5.27, S5.28, S2.16, S3.20: "Initially shows excitement during the game, but enthusiasm faded as the game progressed."
Frustration and Discouragement	The group's frustration grew steadily as they fell behind other groups, impacting both their internal dynamics and individual motivation.	S2.19, S2.16, S5.26, S5.27, S5.28: "Gives up after not finding the right answer" or "felt discouraged".
Inconsistent Participation	Some group members showed minimal engagement, displaying passive behaviors that suggested a lack of investment in contributing actively.	S2.18, S2.19, S3.23, S3.24, 25.27, S5.28: "Shows limited engagement, participating only partially."

3.2. Collaboration during NUMBO

Patterns of collaboration also revealed a clear distinction between effective and ineffective group dynamics. Effective groups, such as Groups 1 and 6, demonstrated organized and strategic collaboration. Roles were clearly assigned, communication was continuous, and peer validation was consistently practiced. Members supported one another in verifying answers and clarifying misunderstandings, resulting in purposeful and task-oriented interaction. The collaborative behaviors observed in these groups are presented in Table 3.

Table 3. Themes on Collaboration of Effective Groups

Themes	Description	Sample Observation
Role Assignment and Strategy Adaptation	Leaders assigned tasks based on team members' strengths, optimizing the group's productivity and efficiency.	G6: "Two members acted as main solvers and others assisted with identifying solution methods."
Continuous Communication	Regular, transparent communication helped maintain alignment on objectives and progress, enabling coordinated discussions and actions.	S1.1, S1.2, S1.3, S4.5, S4.6, S4.9, S6.10, S6.11, S6.12: "Collaborates with groupmates through continuous communication during the game."
Peer Support and Flexibility	Members provided mutual support, adjusted strategies as needed, and trusted each other's abilities, fostering a collaborative environment.	S4.5, S4.7, S4.8, S1.2, S1.3, S6.12: "Encourages groupmates and offers assistance when they struggle."

On the other hand, ineffective groups lacked coordinated strategies and exhibited minimal interaction. In Groups 2, 3, and 5, students rarely communicated and often duplicated tasks or worked in silos. Dominant members took over while others remained passive or disengaged, leading to confusion and limited collective problem-solving. These challenges in group coordination and collaboration are detailed in Table 4.

Table 4. Themes on Collaboration of Ineffective Groups

Themes	Description	Sample Observations
Lack of Structured Strategy	Lack of role definition led to members working independently, often resulting in duplication of efforts and inefficiency.	S2.17, S3.24: "Struggled to follow group strategies due to unclear roles, contributing to ineffective teamwork and slow progress."
Minimal Communication	Infrequent and inconsistent communication among members created gaps in understanding and reduced collaborative efficiency.	S2.18, S2.19, S3.23, S3.24, S5.26, S5.28: "Barely collaborates with groupmates and showed limited interaction."
Absence of Peer Support	Members relied primarily on individual contributions or a dominant member, limiting group cohesion and reducing overall effectiveness in teamwork.	S3.24, S3.23, S5.26, S5.27, S5.28: "Did not show competitiveness or support for groupmates and often working individually"

3.3. Discussion

This study investigated how game-based learning, through the NUMBO intervention, supported student engagement and collaboration during a mathematics performance task. Game-based learning, which integrates educational content with game mechanics such as competition, scoring, and achievement systems, is known to promote cognitive engagement and motivation (Plass et al., 2015). NUMBO, a modified Bingo game, was used to create an interactive and collaborative learning environment where students were encouraged to work together, solve problems, and support each other.

Findings revealed that students in effective groups—particularly Groups 1, 4, and 6—demonstrated high levels of energy, focus, and persistence. These groups benefited from structured role assignments, continuous communication, and mutual support. For example, Groups 1 and 6 assigned specific roles, coordinated consistently, and showed a strong sense of shared responsibility. This is consistent with studies showing that structured group roles foster collaboration and academic success (Gamit et al., 2017). Similarly, Molina and Ibañez (2024) found that structured group tasks, such as those in the KenKen puzzle study, not only enhanced problem-solving but also sustained student motivation through collective effort.

NUMBO's competitive, yet cooperative format also strengthened group cohesion, mirroring research where peer support and shared goals enhanced student persistence and comprehension (Gamit et al., 2017; Aguhayon et al., 2023). Communication played a critical role in maintaining group alignment and promoting adaptive problem-solving (Ford et al., 2020). Regular discussions allowed students to resolve misunderstandings, distribute tasks strategically, and maintain momentum.

Conversely, ineffective groups—namely Groups 2, 3, and 5—struggled with collaboration due to a lack of structure and unclear role distribution. In Group 5, for instance, all members worked independently without coordinating, leading to redundant efforts and rising frustration. Group 2 initially showed enthusiasm but disengaged when the activity became difficult, reflecting the consequences of limited peer support and unclear goals. These behaviors align with prior findings that highlight how the absence of defined roles and communication can fragment group efforts and reduce engagement (Rubin et al., 2014; Tonéis & Paulo, 2023).

The importance of structured collaboration was further underscored by the positive outcomes of groups that utilized members' individual strengths. Role clarity improved efficiency and accountability, consistent with recommendations by Del Rosario (2023), Ebajan and Tamban (2024), and Kroeger and Kouche (2006). In these groups, peer support also fostered an inclusive and trusting environment, helping students approach challenging tasks with confidence and resilience.

In summary, the NUMBO intervention demonstrated that well-structured collaboration—through defined roles, sustained communication, and

peer support—significantly enhances group engagement and effectiveness. However, this study is subject to several limitations. It was conducted within a single setting and involved a relatively small sample size, which may limit the generalizability of the findings. Additionally, the study did not aim to measure actual learning gains, focusing instead on perceived experiences and thematic patterns. These findings echo existing literature on cooperative learning and game-based instruction, reinforcing that intentionally designed interventions can positively influence both the cognitive and socio-emotional dimensions of mathematics learning.

4. CONCLUSIONS

This study examined how the NUMBO intervention—a modified Bingo game—fostered collaboration and engagement among Grade 9 students during a mathematics performance task. Rather than directly measuring improvements in achievement, the study focused on observing how students interacted, communicated, and supported one another throughout the activity. The findings suggest that game-based learning environments, when structured effectively, can promote meaningful group dynamics that enhance student motivation and participation.

Groups that performed well demonstrated a balance of enthusiasm, persistence, and cooperative competition. Their success was driven by structured role assignments, continuous communication, and strong peer support, all of which contributed to focused and resilient teamwork. These findings align with existing research emphasizing the importance of role clarity and interpersonal interaction in collaborative learning contexts. Conversely, groups that struggled lacked coordination, clear goals, and consistent participation. Without defined roles or shared strategies, members often worked in isolation, leading to duplicated efforts, frustration, and eventual disengagement. Unequal participation and the absence of mutual support further contributed to their difficulties, highlighting the need for intentional scaffolding in collaborative tasks.

Based on these insights, teachers are encouraged to integrate structured game-based activities like NUMBO into their instructional practice. Key strategies include explicitly modeling collaborative skills, promoting role delegation, and fostering peer accountability. Encouraging healthy competition and facilitating reflective discussions may also sustain motivation and engagement during challenging tasks.

Future research may explore the long-term impact of game-based learning on collaboration and problem-solving, as well as its application in other mathematical domains and educational settings. Overall, NUMBO demonstrates the potential of structured, interactive learning experiences to cultivate both academic and social skills in the mathematics classroom.

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