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REVIEW ARTICLE

Beyond Cognition: A Socio-Emotional Perspective on Collaborative Learning in Mathematics Education

Fatma Erdoğan[1*], Betül Alper[2], & Sinan Kalkan[3]

[1] Assoc. Prof. Dr., Department of Mathematics and Science Education, Faculty of Education, Fırat University, Elazığ, Türkiye
ORCID: 0000-0002-4498-8634

[2] Ministry of National Education, Fırat University, Elazığ, Türkiye
ORCID: 0009-0009-1078-5642

[3]Asst. Prof. Dr., Department of Special Education, Faculty of Education, Çanakkale Onsekiz Mart University, Çanakkale, Türkiye
ORCID: 0000-0001-6890-6421

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ABSTRACT

Mathematics education entails a multidimensional learning process that involves not only cognitive knowledge acquisition but also students' affective responses and social experiences. In collaborative learning environments, where peer interaction and shared problem-solving are emphasized, these dimensions become even more prominent. Emotions such as fear of making mistakes, low self-efficacy, and academic anxiety can directly influence students' relationship with mathematics. In this regard, it is increasingly important to consider mathematics learning processes not solely through a cognitive lens, but also in conjunction with their socio-emotional components, particularly within collaborative settings. In this context, this study aims to examine socio-emotional interactions that emerge during collaborative learning in mathematics education from a theoretical perspective. In collaborative learning environments, students do more than construct knowledge; they also share and regulate emotions through their social relationships within the group, thereby contributing to the learning process on an emotional level. A review of the literature reveals that positive socio-emotional interactions support students' group participation, self-regulation skills, and conceptual learning, while negative interactions may hinder motivation and collaborative engagement. In particular, emotion regulation and socio-emotional monitoring skills stand out as key mechanisms for ensuring the sustainability of learning processes. Ultimately, the study emphasizes that in order to effectively structure collaborative mathematics learning, it is essential to systematically evaluate emotional and social components alongside cognitive factors.

Keywords: Emotions, socio-emotional interaction, collaborative learning, mathematics education.

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***Corresponding Author:** Assoc. Prof. Dr. Fatma Erdoğan, Fırat University, Türkiye
Email: f.erdogan@firat.edu.tr

INTRODUCTION

Mathematics education is widely recognized as a complex learning domain, often characterized by a high cognitive load coupled with intense emotional responses, which frequently lead to academic anxiety among students. Consequently, understanding and managing emotional processes is of critical importance for the creation of effective learning environments (Yu et al., 2024). While engaging with mathematical concepts, students may experience strong emotions such as fear of making mistakes, low self-efficacy, and anxiety about failure. Nevertheless, the literature has traditionally approached this process predominantly from a cognitive perspective, often neglecting the socio-emotional dimensions involved (Živković et al., 2023).

However, learning is not merely a cognitive activity; rather, it is a multidimensional process shaped by learners' social relationships and emotional experiences. Emotions can significantly influence learning processes—either facilitating or hindering them. For instance, positive emotions such as pride, joy, and curiosity tend to enhance engagement, whereas negative emotions such as anxiety, fear, and frustration may obstruct cognitive performance and active participation (Boekaerts & Pekrun, 2015; Pekrun & Linnenbrink-Garcia, 2014). Thus, in the context of mathematics education, the role of socio-emotional interactions in shaping the quality of the learning experience cannot be overlooked.

One of the most prominent educational approaches in which socio-emotional interactions frequently occur is collaborative learning (Hadwin et al., 2018; Montalvo García et al., 2024; Törmänen et al., 2022). These interactions refer to the communicative and relational dynamics through which students express, share, and collectively shape emotional experiences within a group setting (Bakhtiar et al., 2018; Mänty et al., 2020). The literature suggests that positive socio-emotional interactions-such as encouragement and mutual understanding-contribute to the creation of a constructive learning climate (Korkmaz & Güney-Karaman, 2024), whereas negative interactions may hinder learning processes and group cohesion (Kwon et al., 2014; Näykki et al., 2014; Rogat & Adams-Wiggins, 2015).

Despite this, emotions are often treated as secondary to cognitive processes, rarely being examined as independent constructs within the social context of learning (Järvenoja & Järvelä, 2009). However, recent research (e.g., Garcia et al., 2021; Nguyen et al., 2023; Özhan et al., 2023) has emphasized the importance of investigating socio-emotional processes directly within educational environments.

In this context, the present study aims to examine socio-emotional interactions that emerge during collaborative learning processes in mathematics education from a theoretical standpoint. It also seeks to evaluate the impact of these interactions on students' learning experiences through a holistic lens. Ultimately, the study aspires to deepen our understanding of emotional and social dimensions in mathematics education and offer concrete, pedagogically meaningful recommendations for enhancing instructional practices.

The Role of Emotions in Collaborative Learning

Theoretical approaches to emotions in education have been developed over many years, with most focusing on the critical role of emotional experiences in shaping learning outcomes. In particular, Pekrun and Perry (2013) emphasize that a learner's perceived control over a task and the value attributed to that task directly influence emotional responses, which in turn affect academic performance. Within this framework, it is proposed that positive emotions enhance students' engagement in the learning process, whereas negative emotions may undermine learning motivation and disrupt attentional processes. Thus, emotions experienced during learning are not only motivational in nature but are also closely

intertwined with cognitive processing (Pekrun et al., 2017).

However, emotions are not confined solely to the internal world of the individual. Recent studies have demonstrated that emotions influence learning not only at the individual level but also within group contexts (Li et al., 2022; Nguyen et al., 2023). In collaborative learning environments, emotions are shaped through interactions and relationships among group members (Hadwin et al., 2018; Montalvo García et al., 2024). Therefore, emotions should not be viewed merely as internal, individual experiences, but rather as integral elements of shared social engagement and collective meaning-making (Järvenoja & Järvelä, 2013).

In collaborative learning environments, emotions are becoming an increasingly central focus of educational research. Collaborative learning is not merely a process of knowledge sharing; rather, it involves a multilayered structure that requires cognitive, social, and emotional engagement from all participants (Miyake & Kirschner, 2014). Within this framework, students engage in thinking, analyzing, critiquing, and metacognitive regulation, producing knowledge both individually and collectively (Iiskala et al., 2011). Consequently, collaborative learning is not only an academic practice but also a dynamic social space shaped by interaction, cooperation, mutual support, and shared problem-solving. Hadwin et al. (2018) emphasize that the emotions emerging in collaborative learning are predominantly shaped through interpersonal interactions, directly influencing the group climate. Similarly, Järvenoja and Järvelä (2013) argue that emotions should be considered not only as individual states but also as "shared experiences," shaped and reshaped within the collective context. Students are emotionally influenced by their peers, respond to others' affective states, and regulate their own emotions accordingly. Thus, viewing emotions through a social lens can significantly contribute to the design of more functional and emotionally responsive learning environments.

Importantly, group-level emotions are not limited to individual feelings; they are shared and co-regulated experiences (Li et al., 2022; Nguyen et al., 2023). Within this context, students' emotional experiences within the group influence their sense of belonging, their level of trust, and their attitudes toward teamwork in the classroom (Wetcho & Na-Songkhla, 2022). These interactions can bring about positive changes in how students perceive the learning process, thereby enhancing their motivation and academic self-efficacy. When students find motivational support within the collaborative context, they are more likely to manage their emotions effectively, which positively reflects on their learning engagement (Simão, 2016). Conversely, a lack of trust, respect, or empathy within the group may hinder emotional regulation, leading to cognitive slowdown and decreased task performance (Näykki et al., 2022).

Socio-Emotional Interaction in Collaborative Learning Environments

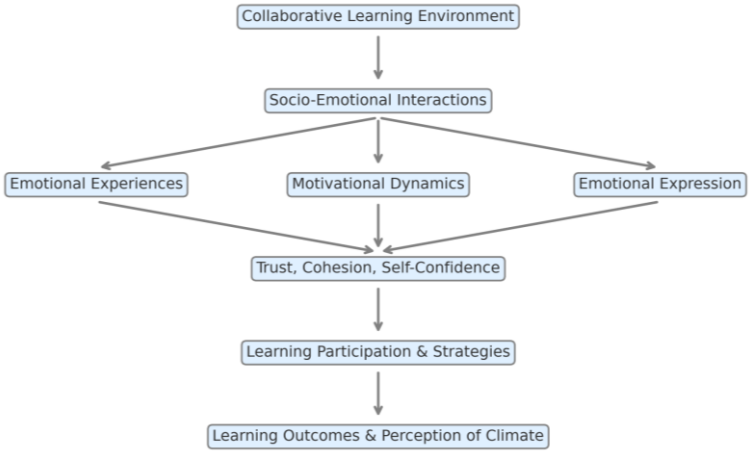
In the context of collaborative learning, the significance of socio-emotional interactions has been increasingly emphasized as a powerful factor influencing learning processes at both the individual and group levels (Huang & Lajoie, 2023; Montalvo García et al., 2024). Over the past two decades, research has consistently shown that emotions can exert a considerable influence not only at the personal level but also at the collective level. Accordingly, theoretical frameworks developed in this area highlight the importance of shared emotions within social contexts and emphasize the role of socio-emotional interaction processes in shaping learning (Hadwin et al., 2018; Li et al., 2022; Nguyen et al., 2023). These interactions may be key determinants of both individual and group success in collaborative learning tasks. In particular, the effective use of socio-emotional regulation strategies by group members has been shown to support more consistent and meaningful progress toward learning goals (Järvenoja & Järvelä, 2009).

Moreover, socio-emotional interactions influence not only the learning outcomes but also students' perceptions of

their learning environments and the emotional climate of the learning community (Korkmaz & Güney-Karaman, 2024). The emotional experiences that students undergo in their classroom or group contexts significantly shape their willingness to collaborate, express their ideas, and build social connections (Järvelä et al., 2016; Wetcho & Na-Songkhla, 2022). When positive socio-emotional exchanges are shared among group members, students tend to develop more favorable attitudes toward teamwork and are more likely to engage in trust-based and motivated group relationships (Hu et al., 2021; Wang, 2018; Zhang et al., 2021). In this way, socio-emotional interactions become not only integral to the learning process but also instrumental in shaping how learners perceive and position themselves within the social dynamics of their groups.

Social interactions serve not only as a foundation for cognitive processes, but also as a medium for sharing emotional experiences. Supportive comments, empathetic responses, and affective feedback help students feel safer within the group context and foster their willingness to engage in learning (Isohätälä et al., 2017). In this regard, socio-emotional interaction encompasses motivational dynamics, emotional expression, and a sense of connectedness among group members. These interactions are not limited to verbal communication; rather, they may also be conveyed through laughter, facial expressions, tone of voice, and other forms of emotional signaling (Li et al., 2024). Bakhtiar et al. (2018) emphasize that socio-emotional interactions are particularly effective in fostering emotional qualities such as trust, cohesion, and self-confidence. Importantly, these interactions are directly linked not only to students' participation in learning tasks but also to the emotions they experience while engaging in those tasks, the cognitive strategies they employ, and the nature of their interpersonal relationships (Huang & Lajoie, 2023). By shaping the social atmosphere of the group, socio-emotional interactions can act as either facilitators or inhibitors of meaningful learning (Näykki et al., 2014, 2021). Figure 1 presents a conceptual model illustrating the dynamic structure of socio-emotional interactions within collaborative learning environments. The model demonstrates how individual and group-level emotional experiences influence learning participation and perceptions of learning outcomes through motivational dynamics and emotional expression. It also highlights that socio-emotional interactions are not only associated with learning outcomes but are directly linked to group trust, cohesion, and the use of cognitive strategies.

Figure 1. Model of socio-emotional interaction in collaborative learning



The Multidimensional Nature of Collaborative Participation: The Role of Cognitive and Socio-Emotional Interactions

In collaborative learning processes, students do more than simply receive information; they actively generate, critique, question, and co-construct knowledge while developing strategies to achieve shared goals (Li et al., 2024). In this context, collaborative participation can be understood as a collective form of interaction in which all group members contribute to the learning process in an active, simultaneous, and meaningful manner (Zheng et al., 2023). This participation is not confined to the distribution of tasks; rather, it encompasses the interplay of social relationships, cognitive engagement, and emotional involvement, making it an inherently multidimensional process (Järvelä et al., 2016). Thus, collaborative learning integrates both cognitive and socio-emotional interactions into a cohesive framework (Li et al., 2024).

Cognitive processes refer to students' efforts to deepen their conceptual understanding through thinking, analyzing, reasoning, and joint knowledge construction. Cognitive interaction, in this sense, involves the exchange and co-development of ideas between two or more learners working toward a common objective (Li et al., 2024). Through such interactions, students participate actively in the co-construction of meaning, sharing their ideas, building upon each other's thoughts, and generating new knowledge collectively (Roschelle, 1992).

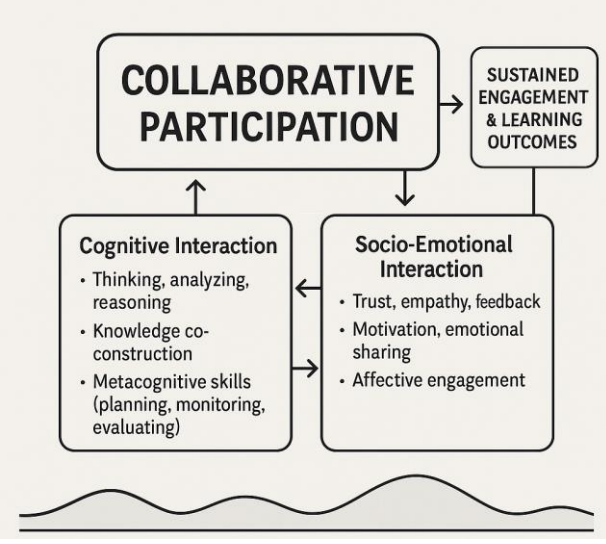
Social interaction is one of the core components of collaborative learning. It enables students not only to share knowledge but also to reconstruct it, critically evaluate perspectives, and approach concepts from multiple angles (Näykki et al., 2021; Roschelle, 1992). It entails mutual communication, the generation of shared meaning, and the joint structuring of learning processes (Cohen, 1994). Moreover, students utilize metacognitive skills during these interactions to regulate their own learning—such as planning, monitoring progress, evaluating outcomes, and adjusting goals (Iiskala et al., 2011; Näykki et al., 2017). However, interpersonal dynamics and environmental factors within the group may either facilitate or hinder participation in collaborative learning. A lack of social interaction can reduce the learning experience to superficial task completion, where students disengage from one another and the learning process becomes mechanistic and uninspired (Näykki et al., 2021).

The sustainability of collaborative participation largely depends on the quality of intra-group interactions. When these interactions occur on both cognitive and socio-emotional levels, students tend to demonstrate more sustained and meaningful engagement in the learning process. Li et al. (2024) emphasize that this dual-layered interaction significantly enhances the overall success of collaborative learning. Similarly, Järvelä et al. (2016) highlight that at the heart of effective collaborative participation lies the integration of cognitive and socio-emotional dimensions of learning. This integration transforms learning from a mere process of knowledge transmission into a dynamic arena of emotional and social engagement.

Studies conducted in online collaborative learning environments have revealed that students often experience fluctuations over time in both cognitive and socio-emotional interaction patterns (Isohätälä et al., 2020). Such variability is critical for understanding how learners adapt to group settings, establish interpersonal relationships, and contribute to shared goals. In this regard, a productive collaborative learning experience entails more than cognitive information processing—it also includes motivational dynamics and emotional exchanges, forming a rich and multidimensional learning structure (Borge et al., 2018). Ultimately, collaborative participation reflects not only individual involvement in knowledge generation but also the strength of social bonds and the overall quality of the emotional climate within the group. Therefore, to achieve an effective collaborative learning experience, it is essential to support both cognitive structuring

and socio-emotional interactions in a balanced and constructive manner. Figure 2 presents a multidimensional model of collaborative participation, highlighting the reciprocal relationship between cognitive and socio-emotional interactions. It shows how students' intellectual engagement and emotional responsiveness jointly contribute to sustained participation and meaningful learning outcomes. The model also reflects the dynamic nature of participation, influenced by group processes over time.

Figure 2. Multidimensional model of collaborative participation



The Qualities of Socio-Emotional Interactions and Their Relationship with the Learning Process

The quality of socio-emotional interactions plays a decisive role in shaping the effectiveness of the learning process. These interactions encompass not only students' cognitive engagement with learning tasks, but also the emotional states and social behaviors that emerge throughout the process (Özhan et al., 2023). Socio-emotional interactions influence students' positions within the group, the strength of their relational bonds, and their attitudes toward shared objectives. Research has shown that positive socio-emotional exchanges create a supportive group atmosphere in which students feel emotionally safe, can express their ideas freely, and are more willing to take academic risks (Näykki et al., 2014). In such contexts, relational competencies such as respect, empathy, active listening, emotional expression, and feedback reception become highly salient (Simão, 2016).

In the literature, socio-emotional interactions are often treated as "intervening variables" or secondary elements linked to learning outcomes. However, examining these interactions as independent objects of study offers deeper insight into the inherently multidimensional nature of learning processes (Garcia et al., 2021). In their study on socio-emotional engagement, Huang and Lajoie (2023) emphasize that these interactions direct students' attention, energy, and emotional resources, thereby enriching their learning experiences. While Näykki et al. (2021) highlight the role of group cohesion in learning success, Sobocinski et al. (2017) argue that the quality of interactions matters more than their frequency. This perspective underscores the importance of analyzing the contextual content of interactions, rather than relying solely on quantitative indicators. Ultimately, socio-emotional interactions shape the quality of students' experiences in classroom

or group environments, strengthening their attitudes toward teamwork and reinforcing their sense of social connectedness (Wang, 2018).

Some studies (Rogat & Linnenbrink-Garcia, 2011) have suggested that positive emotional interactions enhance problem-solving success, while others (Garcia et al., 2021) argue that excessive social bonding may actually constrain cognitive depth. These contrasting findings point to the context-sensitive and dynamic nature of socio-emotional interactions. Therefore, such processes should not be viewed solely through the lens of relational dynamics; rather, they are closely intertwined with task-related perceptions as well.

This becomes especially evident when students are confronted with complex or demanding tasks. In such situations, factors such as trust in the group, emotional support, and mutual understanding tend to become more prominent (Näykki et al., 2017). Conversely, when group cohesion is lacking, the consequences extend beyond the social domain, negatively affecting task monitoring, attentional focus, and cognitive performance (Näykki et al., 2021). These challenges are often labeled as "interaction deficits." However, Linnenbrink-Garcia et al. (2011) argue that when negative emotions are openly expressed and constructively managed, they do not necessarily harm the learning process; in fact, they can sometimes stimulate deeper, task-relevant discussions. This perspective highlights the importance of evaluating emotions not merely in terms of a positive–negative dichotomy, but rather in relation to the specific context and the manner in which they are regulated.

Socio-Emotional Monitoring: The Role of Affective Awareness in Group Dynamics

Socio-emotional monitoring refers to a multidimensional process in which students recognize both their own emotional states and those of their group members, interpret these emotional cues, and develop appropriate social-emotional responses (Kwon et al., 2014). This process aims not only to promote individual awareness but also to maintain emotional balance within the group, thereby sustaining task-focused interactions in collaborative learning environments (Lajoie et al., 2015).

Collaborative learning is not limited to cognitive and behavioral processes; it is also closely linked to how students experience emotions and integrate those emotions into their learning. Particularly before, during, and after group tasks, emotional reactions—such as pride, frustration, anxiety, boredom, anticipation of success, or enjoyment—can directly shape the trajectory and quality of the collaborative process (Baker et al., 2013). These emotions may stem from individual characteristics or emerge from ongoing social interactions within the group (Järvenoja & Järvelä, 2009; Näykki et al., 2014; Van Den Bossche et al., 2006).

Developing socio-emotional monitoring skills requires more than simply feeling emotions; students must understand their function, evaluate their expressions, and regulate them when necessary (Baker et al., 2013). The literature emphasizes that this process is a foundational component for sustaining collaboration and achieving shared goals (Lajoie et al., 2015). However, much of the current research has focused on individual-level monitoring, while collective monitoring processes within group contexts remain underexplored (Kwon et al., 2014). This gap calls for more nuanced analysis of how socio-emotional monitoring unfolds not only as an individual competency but also as a dynamic aspect of group interaction.

Moreover, the literature includes findings suggesting that openly expressing emotions may enhance group cohesion and transparency (Näykki et al., 2014). On the other hand, some studies warn that such expressions can be misinterpreted

and may even lead to interpersonal tension within groups (Van Kleef & Fischer, 2016). These conflicting findings suggest that socio-emotional monitoring must go beyond the mere expression of emotions to include how those emotions are perceived, received, and shape group interactions. In this regard, teachers are encouraged to incorporate classroom activities that foster socio-emotional monitoring skills. Techniques such as emotion journaling, empathy-based group discussions, and reflective practices around emotional expression can help students become more aware of their feelings and manage group emotional dynamics more effectively (Näykki et al., 2022).

Emotion Regulation: Managing the Affective Dimension of Collaborative Learning

The process of emotion regulation refers to individuals' ability to recognize, assess, and consciously manage their emotional experiences, including the type, intensity, and expression of those emotions (Gross, 2013). This process encompasses not only personal self-regulation but also the management of emotions that arise within social contexts and group interactions. In the context of collaborative learning, emotion regulation involves students' capacity to recognize, manage, and transform emotions such as anxiety, anger, pride, or boredom at both the individual and group levels (Järvenoja & Järvelä, 2009; Mänty et al., 2020).

In collaborative learning environments, the effective use of emotion regulation skills is a fundamental requirement for sustaining the learning process (Järvenoja & Järvelä, 2009). Emotions cannot be reduced to internal individual experiences alone; rather, they function as social dynamics that shape and direct the quality of interpersonal interactions among group members. In particular, emotions such as hope for success, pride, anger, or fear of failure—emerging before, during, and after group tasks—have a direct impact on learning experiences through their interplay with interpersonal relationships (Näykki et al., 2022). Therefore, it is essential for educators to integrate emotion regulation practices into classroom activities. Strategies such as deep breathing exercises, positive self-talk, designated reflection time, or individual journaling can support students in managing their emotional states more effectively (Järvenoja & Järvelä, 2009; Pekrun et al., 2017). These practices help maintain emotional equilibrium in the learning environment, enhance students' self-awareness, and foster healthier social interactions within the group.

Emotion regulation is not solely an individual self-control skill; rather, it also operates as a collective process within the social and group domains (Boekaerts, 2011; Schutz & Davis, 2000). The ability of students to perceive not only their own internal emotional states but also the emotions of their peers, and to respond appropriately, constitutes the social dimension of emotional regulation. In this regard, a collective synchronization of emotions—often referred to as "emotional attunement" within the group—represents one of the key conditions for a successful collaborative learning experience (Näykki et al., 2022).

The findings of Mänty et al. (2020) suggest that negative emotions do not always hinder learning; on the contrary, when accompanied by appropriate monitoring and regulation mechanisms, these emotions can become constructive or even motivational forces. This perspective underscores the view that emotions in learning are not solely obstructive; they may also play directive and activating roles. However, in order for this potential to be realized, students must develop not only individual emotional awareness, but also interactional competence and emotional sensitivity at the group level (Li et al., 2024).

In summary, emotion regulation is one of the foundational components for effectively managing the affective dimension of collaborative learning. Nonetheless, current literature often addresses these processes merely in terms of their outcomes, without adequately analyzing the dynamic, transformative, and context-sensitive nature of emotional

experiences. This gap highlights the necessity of addressing emotion regulation skills more systematically, explicitly, and practically in teacher education programs. Creating safe social spaces within instructional settings where emotions can be expressed, and equipping students with strategies to cope with those emotions, can meaningfully enhance the quality of collaborative learning processes.

Assessing Socio-Emotional Interactions in Collaborative Learning

The assessment of socio-emotional interactions in collaborative learning poses significant challenges due to their complex, dynamic, and context-sensitive nature (Yıldırım et al., 2023). As a result, conventional data collection tools often fall short in capturing the full depth of these interactions. Consequently, researchers frequently rely on qualitative methods to render emotions and interactions more visible within learning environments (Huang & Lajoie, 2023). Data sources such as video recordings based on discourse analysis, online text-based discussions, and student journals allow for the coding and analysis of socio-emotional behaviors. These methods are particularly valuable in disciplines such as mathematics education, where emotional responses can vary widely. Through such approaches, it becomes possible to observe students' emotional reactions, motivational fluctuations, and peer support mechanisms in nuanced detail (Iiskala et al., 2011).

Hu et al. (2021) employed video data to code socio-emotional interactions under categories such as "shared task focus," "active contribution," and "emotional support," analyzing their connection to collaborative problem-solving processes. In mathematics classrooms, such analyses are especially useful in identifying how students' emotional experiences evolve while articulating solution strategies. For instance, the anxiety a student feels when struggling with a challenging problem—or the emotional support received from a peer—can be meaningfully captured through discourse-based methods.

Self-report questionnaires are also commonly used to assess socio-emotional dynamics. However, these tools often fall short in reflecting the complexity of socio-emotional processes, especially given that emotions in group interactions tend to fluctuate rapidly and are highly context-dependent (Huang & Lajoie, 2023; Yıldırım et al., 2023). For this reason, recent research has increasingly moved toward employing multi-method approaches. In the context of mathematics education, this might include the combined analysis of classroom video data and student journals, enabling the tracking of emotional patterns throughout the learning process (Blau et al., 2020).

Blau et al. (2020), for instance, evaluated students' perceived learning across cognitive, emotional, and social dimensions. In a similar vein, students' emotional experiences during collaborative activities in mathematics classes can be coded using either digital or paper-based journals. Expressed positive or negative emotions, responses to feedback, and the nature of interpersonal connections within the group are often explicitly present in such reflections. These data not only document students' affective states but also provide valuable insights for educators or researchers to evaluate the effectiveness of emotion regulation strategies applied during the learning process.

In conclusion, the measurement of socio-emotional interactions cannot be limited to a single methodological approach due to its inherently multi-layered structure. In disciplines such as mathematics education, linking these assessments to cognitive processes enables a more holistic analysis of the learning experience. Specifically, identifying students' moment-to-moment emotional responses allows instructional designs to be more responsive to socio-emotional needs, thereby enhancing the overall quality of collaborative learning.

Socio-Emotional Interaction in the Context of Mathematics Education

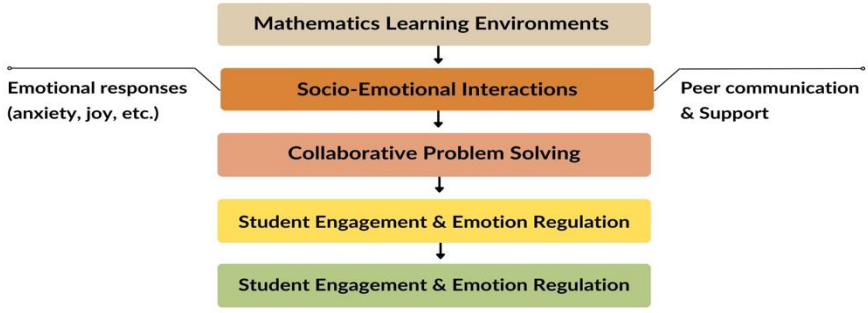
Although mathematics education has traditionally been examined primarily through its cognitive dimension, the influence of affective and socio-emotional components on the learning process has gained increasing recognition in recent years. The emotions experienced by students in mathematics classrooms—such as anxiety, pride, anger, boredom, or joy—are shaped not only individually but also within the broader social context (Hannula, 2006; Pekrun et al., 2017). At this intersection, socio-emotional interactions play a pivotal role. Peer communication, emotional exchanges, and support mechanisms within group settings can significantly influence both individual learning outcomes and the overall quality of the collaborative learning environment (Di Martino & Zan, 2010; Op't Eynde et al., 2006).

The implementation of collaborative learning in mathematics education not only enables students to co-construct knowledge but also offers them the opportunity to jointly regulate the emotions that arise during this process (Järvenoja & Järvelä, 2009). Particularly during problem-solving activities, emotional support or encouragement from peers can help students maintain their self-efficacy beliefs and engage in sustained cognitive effort (Zimmerman & Schunk, 2001).

Students' emotional responses during mathematical tasks are often closely intertwined with group dynamics. A negative group climate may inhibit participation, whereas an empathetic and supportive atmosphere can foster risk-taking behaviors and promote deeper conceptual explanations (Di Martino & Zan, 2010; Op't Eynde et al., 2006). Therefore, cultivating socio-emotional awareness within mathematics learning processes is crucial—not only for enhancing emotion regulation but also for deepening students' engagement and understanding (Hannula, 2006).

The teacher's role in this process is also highly influential. By observing and guiding classroom interactions, teachers can shape not only academic achievement but also students' affective attitudes toward mathematics. Accordingly, the intentional support of socio-emotional interactions in mathematics education represents a valuable instructional strategy for enriching the quality of learning environments. In light of these findings, it would be beneficial for mathematics teacher education programs to include concrete pedagogical strategies for managing socio-emotional dynamics in the classroom. Figure 3 illustrates the socio-emotional interaction process in the context of mathematics education. The model highlights how collaborative mathematics learning environments give rise to socio-emotional exchanges that shape students' emotional experiences, peer communication, and joint problem-solving efforts. These interactions, in turn, contribute to students' engagement and emotion regulation. Ultimately, the teacher's pedagogical role becomes instrumental in guiding both the emotional climate and the quality of learning. The figure emphasizes that socio-emotional processes are deeply embedded within the cognitive and relational dynamics of mathematics classrooms.

Figure 3. Socio-emotional interaction in the context of mathematics education



The Dynamics of Cognitive and Socio-Emotional Interactions in Collaborative Mathematics Learning

In collaborative learning environments, cognitive and socio-emotional interactions serve as fundamental components that shape how learners think, decide, feel, and communicate while working toward shared goals (Isohätälä et al., 2020). These forms of interaction not only involve the exchange of task-related knowledge, but also reflect deeper dynamics such as mutual trust, emotional support, and collective motivation among group members. Within the context of mathematics education, these processes become particularly salient, as students are required to engage in high-level cognitive activities—such as joint problem solving, strategic reasoning, and conceptual explanation—while simultaneously managing complex social-emotional experiences (Di Martino & Zan, 2010; Hannula, 2006).

Task-focused cognitive interaction includes academically oriented collaborative practices such as discussing mathematical content, explaining errors, and comparing problem-solving strategies (Iiskala et al., 2011; Roschelle, 1992). For example, when students work on an algebra problem and explain the representations they use while analyzing each other's solutions, they are not only constructing conceptual understanding but also engaging in social learning. These tasks, however, often involve high cognitive load, uncertainty, and a substantial risk of error—conditions under which socio-emotional support becomes even more essential (Op't Eynde et al., 2006).

In mathematics classrooms, socio-emotional interactions contribute to students' deeper and more sustained engagement with the learning process (Di Martino & Zan, 2010). For instance, offering constructive feedback to a peer's incorrect solution can support both conceptual development and the maintenance of a positive emotional attitude toward learning (Op't Eynde et al., 2006).

Research has shown that positive socio-emotional interactions enhance a sense of trust within the group, thereby encouraging students to take cognitive risks. In contrast, negative emotional dynamics have been associated with reduced participation, social withdrawal, and disengagement from learning activities (Linnenbrink-Garcia et al., 2011). These findings underscore that in disciplines like mathematics, participation in learning is shaped not only by cognitive demands but also by emotional experiences. Therefore, monitoring and supporting both cognitive and socio-emotional interactions in collaborative mathematics learning environments is essential for sustaining meaningful learning processes.

The Dual Role of Mathematics Teachers: Cognitive Instruction and Emotional Facilitation

For mathematics teachers, designing and managing lessons with an awareness of socio-emotional processes can positively influence not only students' academic success but also their attitudes toward the learning experience. Particularly in subjects like mathematics—where societal expectations around achievement often create pressure—it is crucial for students to feel emotionally safe, as such a climate can increase participation and willingness to take intellectual risks (Boaler, 2015; Di Martino & Zan, 2010). When teachers recognize the role of emotions in learning and intentionally create space for students' emotional expressions, mathematics education can become a more humanized and inclusive experience. Classroom observations provide valuable insights into what students feel during learning, enabling teachers to plan both academic and socio-emotional support strategies in a more targeted manner (Op't Eynde et al., 2006).

In collaborative learning activities, observing not only students' cognitive processes but also their emotional interactions with one another—and intervening with structured support when necessary—is a key aspect of effective teacher guidance (Mercer & Sams, 2006). For instance, feelings of disagreement or failure within a group, if approached constructively, can be transformed into powerful sources of intrinsic motivation. However, this transformation is only

possible when teachers foster a learning culture that acknowledges and interprets emotional tensions rather than suppressing them (Wang, 2018). Moreover, it is important for teachers to recognize students' prior experiences and beliefs about mathematics, particularly in relation to emotionally inhibiting factors such as fear of failure or low self-efficacy. To support students in managing these emotional challenges, the creation of open communication channels, empathetic feedback practices, and dialogic, co-constructive learning environments is recommended (Hannula, 2006; Zimmerman & Schunk, 2001). A classroom culture in which students feel free to express their ideas without fear of judgment -and where making mistakes is normalized-supports both emotional regulation and deeper conceptual understanding (Boaler, 2015).

In conclusion, mathematics teachers should not be viewed merely as transmitters of academic content, but also as facilitators of the emotional climate and affective experiences within the classroom. This dual role has the potential to significantly enhance the quality of learning and student engagement. Such an approach reflects a holistic pedagogy that nourishes not only the cognitive aspects of learning, but also its socially constructed emotional dimensions. Furthermore, when teachers initiate dialogues that acknowledge and address emotions in constructive ways, they strengthen students' emotional and cognitive engagement with mathematics lessons.

RESULTS AND DISCUSSION

This study has examined the impact of socio-emotional interactions that emerge during collaborative learning processes in mathematics education through a multidimensional lens. Research has shown that in cognitively demanding domains such as mathematics, students engage in learning not only through mental processes but also via emotional experiences and social relationships (Di Martino & Zan, 2010; Hannula, 2006; Pekrun et al., 2017). Particularly within collaborative learning environments, the emotional dimension of interpersonal interactions becomes as critical as conceptual understanding itself (Järvenoja & Järvelä, 2013; Rogat & Adams-Wiggins, 2015).

Socio-emotional interactions encompass more than the mere sharing of emotions within a group; they also involve the processes of monitoring, regulating, and interpreting emotions within a social context (Kwon et al., 2014; Lajoie et al., 2015; Törmänen et al., 2022). When these interactions contribute to the formation of a positive group climate, they foster students' willingness to take academic risks, reduce fear of making mistakes, and support the maintenance of cognitive effort (Näykki et al., 2014; Zimmerman & Schunk, 2001). Conversely, negative interactions and unregulated emotions have been found to lead to group conflicts and disengagement from learning activities (Linnenbrink-Garcia et al., 2011).

The success of collaborative learning is therefore closely linked not only to the production of academic knowledge but also to the development of social awareness, empathy, and emotional balance among students (Bakhtiar et al., 2018; Järvelä et al., 2016). In this context, skills such as socio-emotional monitoring and emotion regulation serve as essential mechanisms for maintaining group interactions and ensuring continuity in the learning process (Gross, 2013; Mänty et al., 2020). Rather than suppressing emotions, encouraging their open and constructive expression can foster a sense of trust among group members, ultimately creating a more inclusive and emotionally responsive learning environment (Ben-Eliyahu & Linnenbrink-Garcia, 2013).

These findings are particularly significant in the context of mathematics education. Mathematics, as a discipline, not only requires high levels of cognitive effort but also frequently evokes intense affective responses among students (Hannula, 2006; Op't Eynde et al., 2006). Within this framework, the quality of socio-emotional interactions during collaborative learning processes can directly affect students' willingness to share conceptual thinking, their tolerance for

error, and their beliefs in their own competence (Di Martino & Zan, 2010; Järvenoja & Järvelä, 2009). The literature clearly indicates that effective learning environments rely not only on the transmission of content but also on the construction of a supportive socio-emotional climate (Kollar et al., 2018).

In conclusion, evaluating socio-emotional interactions within collaborative learning through a holistic perspective supports the emergence of meaningful, sustainable, and deep learning experiences at both individual and group levels. Developing emotion regulation skills, fostering a positive group climate, and designing learning environments supported by structured scenarios constitute the foundational elements of effective collaborative learning (Hadwin et al., 2018; Järvelä et al., 2013; Malmberg et al., 2015).

RECOMMENDATIONS

This study highlights the importance of integrating socio-emotional dimensions into mathematics education, particularly in collaborative learning contexts. Teachers can design emotionally inclusive classroom environments where students feel safe to express themselves, take academic risks and engage in open communication. Such environments can promote both emotional regulation and deeper conceptual understanding.

To enhance collaborative learning, it is essential to support students' development of emotion regulation and monitoring skills. Simple strategies such as reflective writing, emotion sharing, and empathy-focused discussions can help students better manage their affective states and contribute more meaningfully to group work. Additionally, positive socio-emotional interactions—such as encouragement, active listening, and peer support—should be actively promoted during collaborative tasks.

Teacher training programs should include practical guidance on recognizing and managing classroom emotions. Educators must be equipped not only with cognitive scaffolding tools but also with socio-emotional facilitation strategies. Finally, using multi-method assessment tools—like video observations and student journals—can provide valuable insights into the emotional dynamics of learning, offering a more holistic understanding of students' experiences.

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