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Epistemic Agency in Dialogic Mathematics Teaching: An Explanatory Sequential Design of Online and Offline Contexts

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Abstrak

Pedagogi dialogis memfasilitasi proses berpikir bersama dalam pembelajaran matematika, namun dinamika agensi epistemik pada moda daring dan luring masih jarang dipahami secara mendalam. Penelitian ini menelusuri bagaimana agensi epistemik memengaruhi komunikasi matematis pada dua kelas dialogis yang melibatkan 55 mahasiswa Pendidikan Matematika UIN Siber Syekh Nurjati Cirebon. Melalui desain mixed methods eksplanatori, tahap kuantitatif menilai perbedaan capaian komunikasi, sementara tahap kualitatif menggambarkan pengalaman mahasiswa melalui wawancara dan observasi kelas. Hasil menunjukkan bahwa kelas luring mencapai kinerja komunikasi lebih tinggi, sementara pola capaian komunikasi berbeda secara deskriptif di sepanjang tingkat agensi epistemik. Data kualitatif memperlihatkan bahwa interaksi tatap muka memberi ruang bagi inisiatif spontan, penilaian sejawat yang lebih kaya, serta alur diskusi yang lebih fleksibel. Sebaliknya, interaksi daring cenderung membatasi partisipasi. Temuan ini menunjukkan bahwa agensi epistemik tidak hanya hadir dalam proses dialogis, tetapi juga berkelindan dengan capaian komunikasi, dengan implikasi bagi rancangan pembelajaran dialogis yang lebih adil.

***Kata Kunci**: Pedagogi dialogik; agensi epistemik; komunikasi matematis; modalitas pembelajaran; metode campuran; pengajaran dialogis; pembelajaran daring.*

Abstract

Dialogic pedagogy provides a foundation for cultivating reasoning and communication in mathematics; however, the emergence of epistemic agency across learning modalities remains underexplored. This study investigated how epistemic agency relates to mathematical communication in online and offline dialogic settings, employing an explanatory sequential mixed-methods design with 55 mathematics education students at UIN Syekh Nurjati Cirebon. The quantitative phase employed a quasi-experimental approach supported by validated instruments, while the qualitative phase drew on interviews and classroom observations. The results indicate that offline learning produced higher communication performance, with descriptive differences in communication patterns observed across levels of epistemic agency. Qualitative evidence illustrated how offline interaction encouraged initiative, appraisal, framing, and shared involvement, whereas online environments tended to constrain these expressions. The study highlights distinct enactments of epistemic agency across modalities and their implications for dialogic mathematics instruction.

Keywords: Dialogic pedagogy; epistemic agency; mathematical communication; learning modality; mixed methods; dialogic teaching; online learning.

I. INTRODUCTION

Dialogic pedagogy continues to influence how mathematics educators approach learning. Its appeal lies in the way classroom talk allows ideas to unfold, sometimes slowly as students test early interpretations, and sometimes in sudden moments of shared insight. Studies in recent years have shown that dialogue can strengthen collective reasoning and help learners sustain attention to one another's thoughts. It creates conditions where mathematical meaning develops through a rhythm of inquiry that involves offering, examining, and revisiting ideas (Ulkhaq, 2023; Alexander, 2020; Howe et al., 2019; Mercer & Littleton, 2007).

In spaces where dialogue becomes part of students' daily work, mathematical activities tend to unfold differently. Claims are explained with greater care, disagreements become starting points for refinement, and students develop a sense of ownership over emerging explanations. Research has noted that these interactions reveal how learners participate in disciplinary reasoning, often by interpreting problems together or challenging the logic of a peer's statement (Susanti et al., 2023; Howe et al., 2019; Kim & Wilkinson, 2019; Ruthven et al., 2017). These observations have drawn scholarly attention to epistemic agency, a construct that captures how individuals introduce new lines of thought, evaluate the reasoning that circulates within the group, and help shape the direction of ongoing inquiry. Recent contributions describe agency as a process that grows through repeated opportunities to share, coordinate, and refine ideas within a social setting (Nieminen & Ketonen, 2024; Tan et al., 2022; Zhan & Louie, 2024).

In this study, epistemic agency is defined operationally as students' responsibility for advancing shared mathematical knowledge through initiating ideas, appraising peers' reasoning, framing problem-solving directions, and sustaining collective inquiry. Grounded in sociocultural perspectives, epistemic agency is understood as an epistemic stance toward knowledge building rather than a mere display of participation, expressed when students take responsibility for proposing, evaluating, and coordinating ideas that shape classroom discourse and mathematical meaning (Damşa et al., 2010; González-Howard & McNeill, 2020; Nieminen & Ketonen, 2024; Stroupe, 2014). This operationalization provides a clear analytic lens for examining how epistemic agency is enacted and differentiated across online and offline dialogic learning contexts.

The expansion of online and blended instruction has shifted the landscapes in which these processes occur. When learners meet in the same physical space, they rely on subtle cues to follow the flow of conversation and determine when to speak. This immediacy often supports the momentum of dialogic activity, and students can sense how their peers respond to a line of reasoning or whether a moment requires clarification or elaboration (Arwadi et al., 2024; Zheng & Shi, 2025). In digital environments, the dynamics change. Participation can become fragmented, nonverbal responses are less visible, and small delays influence how students perceive the orientation of the discussion. Several studies describe how these

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conditions reshape participation structures by limiting spontaneity and narrowing access to the cues that help learners stay aligned with one another's thinking (Rapanta et al., 2021; Rios, 2024).

Face-to-face learning continues to offer possibilities that are not always replicated online. Students can respond to a peer's idea almost immediately, and this proximity often encourages them to test alternative explanations or reorganize the pathway through a task. Offline environments tend to support richer forms of appraisal because students can track reasoning as it evolves and respond to it with greater nuance (Permatassari & Afriansyah, 2022; Capriati, 2024). There are moments when an explanation shifts direction simply because someone sees it differently, and these acts of reframing signal a developing sense of epistemic responsibility (Mirza & Pasaribu, 2024; Wells, 1999; Zhang et al., 2025). Accounts from online learners often tell a different story, where the momentum of the discussion rests more heavily on the instructor, and opportunities to redirect the task are fewer.

Scholars have also emphasized the theoretical importance of noticing how agency becomes visible in discourse. Bishop (2021) highlights the role of responsiveness to intellectual work in supporting conceptual growth, while Garcia and colleagues (2020) point to dialogic conditions that encourage learners to take part in the reasoning work of the group. In digital contexts, researchers have observed instances where this participation becomes more limited (Yumna et al., 2025). Evaluative dialogue becomes brief, unfolding in comments that confirm rather than interrogate ideas, and some learners begin to contribute from the margins with limited opportunities to shape the activity (Engeness & Nohr, 2020; Ng et al., 2021; Efwan et al., 2024). These patterns raise questions about how modality shapes learners' access to the interactional resources that sustain agency.

Empirical evidence on this issue remains relatively sparse. Studies on mathematics learning increasingly highlight the value of agency-rich interactions for conceptual transfer and problem-solving, yet comparisons across modalities remain limited (Li & Xue, 2023; Martin et al., 2022). Accordingly, this study does not aim to position one modality as superior, but to examine how different interactional affordances shape the expression of epistemic agency and inform the design of dialogic and hybrid mathematics instruction, a concern that has become increasingly salient in post-pandemic higher education (Nieminen & Ketonen, 2024). By integrating quantitative comparisons with qualitative analyses of classroom interaction, this study seeks to clarify how modality-specific conditions mediate the relationship between epistemic agency and mathematical communication.

The present study examines how epistemic agency influences mathematical communication in dialogic teaching across online and face-to-face contexts. An explanatory sequential mixed methods design guides the analysis. Quantitative findings reveal performance patterns across modalities, while qualitative observations trace how agency is enacted moment by

moment during trigonometry discussions. Bringing these strands together offers a grounded account of how modality interacts with agency and contributes to ongoing conversations about dialogic pedagogy, epistemic positioning, and equitable participation in mathematics education.

II. METHOD

This study employed an explanatory sequential mixed-methods design, which enabled the identification of quantitative patterns in students' mathematical communication before exploring qualitatively how epistemic agency emerged in dialogic interactions. The design was chosen to illuminate not only the outcomes of instruction but also the mechanisms that shaped those outcomes, as interactional moves and reasoning processes often become clearer when examined closely and in context (Creswell & Clark, 2018; Kiger & Varpio, 2020). The study was grounded in sociocultural perspectives that view learning as a discursive and socially situated activity, making a mixed-methods approach well-suited for capturing the interplay among agency, participation, and instructional modality (Mercer & Littleton, 2007; Säljö, 2010).

The quantitative phase compared two intact undergraduate classes from the Mathematics Education Department at UIN Siber Syekh Nurjati Cirebon. Class A included twenty-seven students who participated in synchronous online dialogic teaching, while Class B consisted of twenty-eight students who engaged in face-to-face dialogic instruction. Both classes completed a seven-week trigonometry sequence within the Basic Mathematics Concepts course and undertook pretests and posttests to measure initial proficiency and subsequent gains. For the qualitative strand, six students were selected through maximum variation sampling to represent high, moderate, and low levels of improvement, along with one lecturer from each instructional modality. The selection of participants for the qualitative phase was explicitly informed by the quantitative results, with students chosen based on their levels of learning gain (high, moderate, and low) in order to explain and elaborate the patterns identified in the quantitative analysis. This strategy ensured that the qualitative analysis reflected a broad spectrum of epistemic orientations and interactional experiences during dialogic learning (Heikkilä et al., 2023).

Two instruments were used to assess mathematical communication and epistemic agency. The Mathematical Communication Skills Test was designed for trigonometry and evaluated reasoning, the use of mathematical representations, and the ability to justify solutions in a dialogical manner. The Epistemic Agency Questionnaire was adapted from earlier work by Ruthven and Hofmann (2017) and Zhou et al. (2025), with a focus on initiative, appraisal, and framing. Expert review by three mathematics education specialists yielded Aiken's V values between 0.82 and 0.91, indicating strong content validity. Reliability testing produced Cronbach alpha coefficients of 0.84 for the communication test and 0.86 for the agency questionnaire. Both classes participated in dialogic teaching shaped by Alexander's principles of collective, reciprocal, supportive,

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cumulative, and purposeful dialogue. Online instruction took place through a learning management system that integrated breakout rooms and digital whiteboards, while the face-to-face class engaged in spontaneous turn-taking and embodied interaction. These contrasting environments offered a natural setting for observing how epistemic agency unfolded across modalities (Rios, 2024; Zhou et al., 2025).

The qualitative phase traced how epistemic agency emerged through interactional moves across seven recorded sessions from each class. Analysis of video and transcript data enabled the identification of indicators of initiative, appraisal, framing, and engagement, paying attention to hesitations, affirmations, shifts in tone, or overlaps that often signal changes in epistemic positioning (Ford & Forman, 2006; Howe et al., 2019). Semi-structured interviews with selected students and lecturers provided further insight into how participants interpreted opportunities to express agency, constraints they encountered, and dialogic moments that shaped their communication.

Quantitative data were analyzed using descriptive statistics and inferential procedures. ANCOVA was used to determine whether differences between the two groups remained significant after controlling for pretest scores (Field, 2024), while a moderation analysis examined whether epistemic agency influenced the relationship between instructional modality and mathematical communication. Effect sizes were estimated using Cohen's d. The qualitative analysis employed a hybrid coding approach, combining deductive codes derived from the epistemic order framework with inductive themes that emerged from repeated engagement with the transcripts and interview accounts (Kiger & Varpio, 2020). Constant comparison helped refine categories and ensured consistency across participants and modalities.

Integration of quantitative and qualitative findings followed Creswell and Plano Clark's joint display technique, which positions results side by side to reveal convergences and strengthen explanatory insight (Creswell & Clark, 2018). This approach enabled the study to examine not only whether the two modalities differed in communication performance but also how distinct expressions of epistemic agency contributed to those differences. Joint displays have been recognized as an effective analytical tool in dialogic pedagogy research because they make visible the connections between interactional processes and learning outcomes (García-Carrión et al., 2020; Mercer & Littleton, 2007).

To ensure methodological rigor, content validity and reliability were established in the quantitative phase, while the qualitative phase incorporated member checking, peer debriefing, and triangulation of observations and interviews. An audit trail was documented to support transparency and trustworthiness, detailing analytic decisions throughout the study.

III. RESULT AND DISCUSSION

A. Result

The quantitative analysis begins by reviewing the descriptive statistics of pretest and posttest mathematical communication scores across the two learning modalities. Table 1 summarizes these results, including the gain scores and normalized gains that reflect students' learning progress during the study.

Table 1.

Descriptive statistics of pretest and posttest mathematical communication scores (Mean /Standard Deviation)

Group	N	Pre test	Post test	Gain	N-gain
Online (Class A)	27	45.33 /7.21	72.15 /8.64	26.82 /6.18	0.49
Offline (Class B)	28	46.11 /6.84	78.04 /7.92	31.93 /5.77	0.59

Table 1 shows that both groups experienced considerable improvement in mathematical communication after seven weeks of dialogic teaching. The online group's mean score increased from 45.33 to 72.15, while the offline group rose from 46.11 to 78.04. Normalized gains indicate that the offline group achieved a higher learning effectiveness (g = 0.59, medium–high) compared to the online group (g = 0.49, medium). This suggests that face-to-face dialogic interactions may have provided richer opportunities for communication and negotiation of meaning.

Table 2.

ANCOVA results for posttest scores (controlling for pretest)

Source	SS	df	MS	F	p	Partial η^2
Pretest (covariate)	112.47	1	112.47	3.28	.076	.058
Group (Online vs Offline)	326.84	1	326.84	9.51	.003*	.149
Error	1840.12	52	35.39			
Total	6732.19	55				

- p < .01

The ANCOVA analysis (Table 2) confirmed that group differences remained significant after controlling for pretest scores. The effect of the pretest was not statistically significant (p = 0.076), but the group effect was significant (F = 9.51, p = 0.003). The effect size (partial η^2 = 0.149) indicates a medium impact, suggesting that the mode of dialogic teaching (online vs offline) contributed meaningfully to differences in mathematical communication performance.

Table 3.

Moderation analysis: Epistemic agency as a moderator

Predictor	B	SE	β	t	p
Pretest (control)	0.27	0.14	.21	1.91	.062
Group (0 = online, 1 = offline)	4.83	1.42	.34	3.39	.001*
Epistemic agency (EAQ)	0.45	0.11	.37	4.02	.000*
Group × EAQ (interaction)	0.31	0.12	.29	2.58	.013*

- p < .05

The moderation analysis (Table 3) revealed that epistemic agency significantly influenced the relationship between learning mode and mathematical communication outcomes. Both the main effect of agency (β = 0.37, p < 0.001) and the interaction term (β = 0.29, p = 0.013) were significant. This means that students with higher levels of epistemic agency benefited disproportionately from face-to-face

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dialogic teaching, achieving stronger gains in communication. In contrast, students with lower agency levels showed less improvement, especially in the online context where dialogic engagement was more constrained.

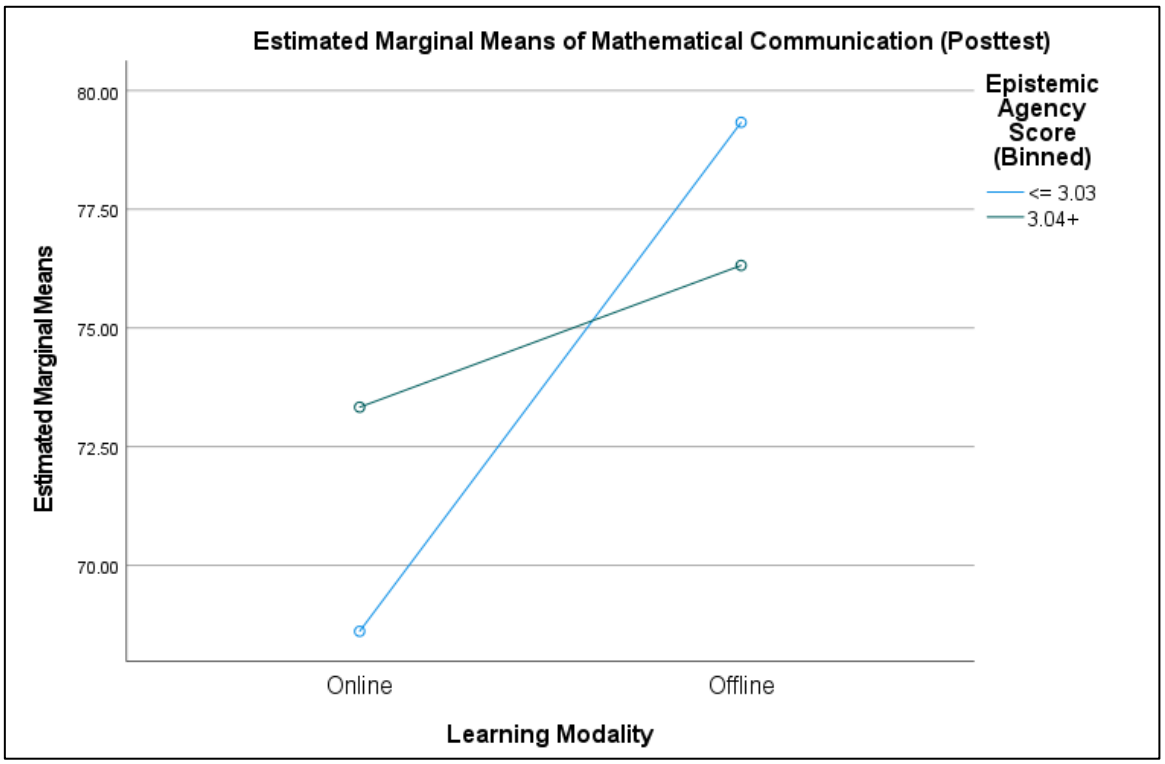

Figure 1. Interaction plot showing the relationship between learning modality and mathematical communication across levels of epistemic agency.

Figure 1 illustrates the interaction pattern between learning modality and epistemic agency in relation to students' mathematical communication performance. Consistent with the quantitative results, students in the offline dialogic class achieved higher posttest scores than those in the online class across both levels of epistemic agency, indicating a clear main effect of learning modality. The interaction plot further reveals that the magnitude of improvement from online to offline settings varied across agency levels, with a more pronounced gain observed among students with lower epistemic agency. Although the interaction effect did not reach statistical significance when epistemic agency was dichotomized, the visual pattern suggests that face-to-face dialogic environments may provide more supportive conditions for students with weaker agency to engage in mathematical communication. This pattern is coherently explained by the qualitative findings, which show that offline interactions enabled more spontaneous initiative, richer peer appraisal, flexible problem-solving framing, and broader engagement, particularly for students who were less active in online settings.

Qualitative data were analysed to capture expressions of epistemic agency in both learning modalities. Four themes emerged: epistemic initiative, epistemic

appraisal, epistemic framing, and engagement style. Table 4 summarizes key patterns and supporting quotations.

The qualitative patterns reveal noticeable contrasts in how agency took shape. In the online class, students frequently showed hesitation, and their participation often depended on the lecturer's prompts. Initiatives emerged gradually, evaluations were often brief, discourse was closely tied to instructional slides, and engagement was limited to a small group. Offline discussions unfolded differently. Students initiated questions more readily, offered substantive feedback on their peers' reasoning, reframed problem-solving steps when necessary, and contributed to a dialogue that developed through shared exchanges. Lecturers' accounts confirmed that these in-person settings created a more supportive environment for distributed agency.

Table 4.
Themes of epistemic agency in dialogic mathematics teaching: Online vs offline contexts

Theme	Online Class (Class A, n=27)	Offline Class (Class B, n=28)	Interpretation
Epistemic initiative (student-led questioning, proposing ideas)	*"I wanted to ask, but I felt unsure to speak on Zoom, so I just typed in the chat."* (SA2, interview) *"Sometimes I had questions, but I waited until the lecturer asked first."* (SA3, interview) *"In online class, only the same students are brave enough to initiate discussion."* (L1, lecturer interview)	*"I often ask my friends directly, like 'why do you use this method?' because we can talk face-to-face."* (SB1, interview) *"I like to start by showing my own solution on the whiteboard."* (SB2, interview) *"In the classroom, students quickly ask questions without waiting for me."* (L2, lecturer interview)	Offline setting enabled **spontaneous and frequent initiatives,** while online initiatives were **hesitant, delayed, and concentrated among a few students.**
Epistemic appraisal (evaluating, critiquing, validating)	*"Usually I just say 'agree' in chat when the lecturer asks. I don't want to cause conflict."* (SA3, interview) *"We rarely comment on each other's answers, only when the lecturer points to us."* (SA1, interview) *"Appraisal in Zoom is very short, mostly yes/no."* (L1, lecturer interview)	*"If my friend explains, I try to check if the graph or formula is right. Sometimes I tell them: maybe your step is wrong here."* (SB2, interview) *"I sometimes compare my answer with theirs and say: yours is better because it is shorter."* (SB3, interview) *"In class, students naturally give feedback to each other without my instruction."* (L2, lecturer interview)	Appraisal practices were **peer-driven, elaborated, and authentic in offline** settings, but **minimal and lecturer-driven in online** contexts.
Epistemic framing (structuring discourse, setting direction)	*"The lecturer gave the steps, so I just followed the worksheet. I didn't change anything."* (SA1, interview) *"In online mode, we just stick to the slides and don't change the flow."* (SA2, interview) *"Students rarely redirect discussion; they follow what I present."* (L1, lecturer interview)	*"Sometimes I suggested using another representation, like drawing a triangle instead of only equations."* (SB3, interview) *"I told the group: let's start with the graph, not the formula."* (SB1, interview) *"Offline discussions allow them to take the lead and reorganize the task."* (L2, lecturer interview)	Offline framing demonstrated students' ability to restructure problems, whereas online framing remained **lecturer-controlled and linear**.

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Theme	Online Class (Class A, n=27)	Offline Class (Class B, n=28)	Interpretation
Engagement style	*"In Zoom, usually only 4 or 5 students are active. The rest are silent or just put emojis."* (L1, lecturer interview) *"I often turn off the camera and just listen. I don't always join the talk."* (SA3, interview) *"We engage more in chat than in speaking, but not everyone types."* (SA2, interview)	*"In class, many students talk, even with short answers, and they respond quickly to each other."* (L2, lecturer interview) *"I like it when my friend continues my explanation, it feels like teamwork."* (SB1, interview) *"We often build on each other's sentences, not just the teacher's."* (SB2, interview)	Offline engagement was **distributed, collective, and reciprocal**, while online engagement was **selective, dominated by a few, and limited to text/chat**.

Students in the online class rarely initiated discussion independently. Several described holding back until the lecturer intervened, as reflected in SA3's comment, "*Sometimes I had questions, but I waited until the lecturer asked first*," and SA2's account, "*I wanted to ask, but I felt unsure to speak in Zoom, so I just typed in the chat.*" L1 noted that only a few students consistently initiated dialogue. Offline interactions presented a different rhythm. Students asked one another direct questions, such as "*Why do you use this method?*" (SB1), and volunteered to present their work at the board, which L2 described as a natural part of the class flow.

These differences suggest that face-to-face learning encouraged quicker initiative and stronger confidence. The online environment, on the other hand, seemed to narrow opportunities for students to step forward, partly because communication tools shaped how and when they spoke. As a result, participation clustered among a small subset of students.

A similar pattern appeared in peer appraisal. In the online class, evaluations were brief and mostly prompted by the lecturer. SA3 commented, "*Usually I just say 'agree' in chat when the lecturer asks*," while SA1 noted that peer responses were rare without explicit direction. L1 observed that evaluation tended to take the form of short confirmations. Offline discussions involved richer and more analytical appraisal. SB2 shared, "*Sometimes I tell them: maybe your step is wrong here,*" and SB3 compared alternative approaches by noting, "*Yours is better because it is shorter.*"

These interactions demonstrate that the offline setting facilitated more authentic evaluative dialogue, enabling students to examine and refine each other's reasoning in greater depth. In contrast, online appraisal remained shallow and closely tied to lecturer guidance, which limited students' opportunities to build on their peers' ideas.

Differences also emerged in how students framed mathematical tasks. Online discourse usually followed the lecturer's structure quite closely. SA1 stated, "The lecturer gave the steps, so I just followed the worksheet," and SA2 noted that "we just stuck to the slides." L1 confirmed that students seldom redirected the discussion. Offline students occasionally reorganized tasks or introduced new representations.

SB3 recalled suggesting alternative visualizations, and SB1 encouraged starting from a graph rather than following formulaic steps.

These moments illustrate a greater sense of ownership during offline discussions. Students could shift the direction of the task when needed, whereas online settings encouraged a more linear and teacher-directed flow, making such reframing less common.

Engagement also differed sharply. Online discussions typically involve only a few active participants. L1 mentioned that "in Zoom, usually only 4 or 5 students are active," and SA3 admitted to turning off the camera and remaining silent. SA2 added that chat activity did not always translate into spoken participation. Offline sessions demonstrated broader involvement, with students responding to one another more quickly, as L2 noted.

Students' reflections align with this pattern. SB1 appreciated when peers extended his explanations, and SB2 remarked that "We often build on each other's sentences." These exchanges reflect a form of collective engagement that is rarely seen online, where contributions tend to be more fragmented and shaped by technological constraints.

Table 5.
Comparative Patterns of Epistemic Agency in Online and Offline Dialogic Mathematics Teaching

Phase / Dimension	Online Dialogic Teaching	Offline Dialogic Teaching	Comparison Insight	Coded Theme
Initiative	• Students mostly typed in chat rather than speaking. • Initiative concentrated in a few active voices. • Reliance on lecturer prompts.	• Students verbally initiated questions without waiting. • The initiative spread across many participants. • Spontaneous idea-sharing occurred.	The online initiative was selective and mediated; the offline initiative was spontaneous and distributed.	Selective vs. Collective Agency
Appraisal	• Peer evaluation limited to short confirmations (“agree," “yes”). • Rarely involved justification.	• Extended peer critique with reasoning. • Students compared strategies and identified errors.	Offline appraisal showed epistemic depth, while online appraisal was surface-level.	Surface vs. Elaborated Evaluation
Framing	• Discourse tightly followed the lecturer's slides. • Minimal student-led reframing of tasks.	• Students reframed tasks by suggesting graphs or alternative approaches. • More flexible discourse organization.	Offline framing reflected student ownership; online framing remained teacher-dependent.	Teacher-Led vs. Student-Led Framing
Engagement	• Engagement uneven, dominated by 4–5 students. • Many remained silent with cameras off.	• Broader participation across students. • Exchanges are cumulative and iterative.	Offline engagement was inclusive; online engagement was selective.	Uneven vs. Inclusive Participation

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The comparative Table 5 shows that epistemic agency in online contexts tended to be selective and constrained, while in offline settings it appeared distributed and generative. In terms of initiative, online students mostly depended on lecturer prompts and expressed themselves through chat, resulting in participation that clustered around a few individuals. In contrast, offline students voiced questions more freely and shared ideas spontaneously, allowing initiative to circulate more evenly across the group.

A similar contrast is visible in appraisal, framing, and engagement. Online students often limited their responses to short confirmations, adhered closely to lecturer guidance, and showed uneven engagement. By comparison, offline students engaged in extended peer critique, reframed problems with alternative approaches, and participated more inclusively. These differences suggest that offline learning created richer conditions for students to claim and negotiate epistemic roles, whereas online learning produced more surface-level interaction and concentrated agency.

Table 6.
Joint display of quantitative and qualitative results on epistemic agency in dialogic mathematics teaching

Quantitative Results	Qualitative Findings (Themes + Illustrative Quotes)	Meta-Inference (Integration)
Offline students (M = 78.04) scored significantly higher than online students (M = 72.15) in mathematical communication (ANCOVA, $p = .003$, $\eta^2 = .149$).	Epistemic Initiative (EI1–EI6): Offline students-initiated questions and proposed ideas spontaneously ("I often ask my friends directly…" – SB1; "I like to start by showing my solution…" – SB2), while online initiatives were hesitant and often text-based ("I just typed in the chat" – SA2).	Higher communication scores in offline settings are partly explained by richer student-led initiatives that allowed ideas to emerge, circulate, and be elaborated through direct dialogue.
Differences in mathematical communication between online and offline settings showed varying patterns across levels of epistemic agency (see Figure 1).	Epistemic Appraisal (EA1–EA6): Offline students engaged in substantive peer critique ("Maybe your step is wrong here" – SB2; "Yours is better because it is shorter" – SB3), whereas online appraisal was brief and confirmatory ("Usually I just say 'agree' in chat" – SA3).	The qualitative evidence suggests that offline dialogic environments provided conditions that enabled students to express epistemic agency more fully through peer evaluation, helping explain the visual interaction pattern observed in Figure 1.
Normalized gain was higher in the offline class (g = 0.59, medium–high) than in the online class (g = 0.49, medium).	Epistemic Framing (EF1–EF6; FI1–FI6): Offline students occasionally reframed tasks by proposing alternative representations ("Let's start with the graph…" – SB1), while online discourse largely followed the lecturer's slides ("We just stick to the slides" – SA2).	Greater learning gains in the offline class align with students' capacity to reframe mathematical problems, supporting deeper conceptual understanding and more coherent communication.
Selective engagement was observed in the online setting, with participation concentrated among a small number of students.	Engagement Style (EG1–EG6; EGI1–EGI6): Online participation was uneven ("Only 4 or 5 students are active" – L1; "I often turn off the camera…" – SA3), whereas offline engagement was broader and cumulative ("Many	Broader and more inclusive engagement in offline contexts fostered collective dialogue and supported mathematical communication, while fragmented

Quantitative Results	Qualitative Findings (Themes + Illustrative Quotes)	Meta-Inference (Integration)
	students talk…" – L2; "We often build on each other's sentences" – SB2).	online engagement constrained the distribution of epistemic roles.

The integration of quantitative and qualitative results offers a clearer view of how epistemic agency shaped students' mathematical communication across learning modalities. The joint display from Table 6 illustrates how the quantitative patterns align with the qualitative accounts, clarifying why the offline class achieved higher levels of mathematical communication. Students who met in person exhibited fuller expressions of epistemic agency, characterized by spontaneous initiatives, deliberate peer appraisal, flexible problem reframing, and dialogue that progressed through shared contributions. In contrast, the online class exhibited hesitant participation, brief evaluations, and a discussion flow heavily guided by the lecturer, with most interaction concentrated among a small group. The moderation analysis reinforces this interpretation, showing that students with stronger epistemic agency were better positioned to take advantage of the interactional space available in offline sessions, while those with lower agency found online participation more restrictive.

Quantitative results support this pattern. Students in the offline class (M = 78.04) outperformed those in the online class (M = 72.15) after seven weeks of dialogic teaching (ANCOVA, $F = 9.51$, $p = .003$, $\eta^2 = .149$), and their normalized gain reached a medium high level ($g = 0.59$) compared to the online group's medium gain ($g = 0.49$). These improvements align with the qualitative evidence, where offline students readily initiated dialogue, as evident in statements such as "*I often ask my friends directly*" (SB1) and "*I like to start by showing my solution on the whiteboard*" (SB2). Online students described feeling uncertain when contributing verbally ("*I wanted to ask, but I felt unsure to speak in Zoom, so I just typed in the chat*" SA2), and L1 noted that only "*the same few students*" routinely initiated discussions.

The moderation analysis further highlights how agency shaped outcomes. Students with higher epistemic agency benefited more from offline instruction, which offered richer opportunities for critique and collaborative reasoning. Offline participants frequently engaged in detailed peer appraisal, as illustrated by remarks such as "*Maybe your step is wrong here*" (SB2) and "*Yours is better because it is shorter*" (SB3). Appraisal in the online setting, however, remained minimal and was often tied to lecturer prompts ("*Usually I just say agree in chat when the lecturer asks*," SA3), limiting the potential for students to extend one another's ideas.

Patterns of engagement complete this picture. Although online learning produced moderate improvement, participation was selective, with only four or five active voices in most sessions (L1) and several students choosing to remain silent or off camera (SA3). The offline class displayed broader and faster exchanges, with students frequently building on each other's contributions, as reflected in SB2's comment that "We often build on each

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other's sentences." Taken together, these findings show that the offline learning environment created more supportive conditions for epistemic agency to emerge across initiative, appraisal, framing, and engagement, which helps explain the stronger communication outcomes observed.

B. Discussion

The quantitative findings showed a clear pattern. Students who participated in face-to-face dialogic teaching demonstrated stronger gains in mathematical communication than their peers who learned online. This contrast aligns with observations in earlier work, where shared physical space facilitates the coordination of attention and enables learners to follow the flow of talk with greater ease. In settings where the dialogue unfolds in real time, students can observe shifts in tone, posture, or emphasis, and these cues help them track how mathematical ideas are being shaped within the group (Alexander, 2020; Mercer & Littleton, 2007; Zheng & Shi, 2025). Such affordances create conditions that make it easier for students to verbalize emerging interpretations, work through partial explanations, and test the validity of their reasoning in conversation with peers (Kim & Wilkinson, 2019; Ruthven et al., 2017).

The qualitative evidence adds texture to this picture. In the offline class, students entered discussions with a sense of immediacy. They asked questions without hesitation, responded to each other's ideas with confidence, and offered solutions in ways that invited further elaboration. These behaviors reflect what Zhan and Louie (2024) describe as sensitivity to the subtle rhythms of in-person interaction. In the online class, however, learners often paused before speaking or shifted their contributions into short chat messages. Their hesitation reflects challenges reported in research on synchronous digital environments, where reduced visibility and weaker social cues can dampen students' readiness to engage in exploratory talk (Rapanta et al., 2021; Rios, 2024).

The moderation analysis provides another layer of insight. Epistemic agency influenced how fully students benefited from dialogic instruction. Those with higher agency gained more from offline settings, suggesting that opportunities to initiate interpretations, probe peers' thinking, or reorganize the task were strengthened by the fluidity of co-present interaction. This aligns with Zhou et al. (2025) and with a view of González-Howard and McNeil (2020), who characterize agency as a way of taking up positions within the discourse and guiding its trajectory.

The qualitative data illustrate how these processes played out in practice. Offline learners engaged in extended appraisal, comparing lines of reasoning and considering alternative solution paths. These moments of evaluative dialogue resemble the conditions that Bishop (2021) identifies as productive for intellectual growth. Online learners rarely sustained such exchanges. Their appraisal tended to be brief and confirmatory, a pattern consistent with Ng et al., (2021) observations that technological mediation can limit the depth and persistence of evaluative talk.

Differences in epistemic framing added further contrast between modalities. Offline students sometimes shifted the direction of problem-solving by proposing new ways to represent a situation or by reframing a task entirely. These moves signaled their sense of ownership over the inquiry. This type of reframing has long been associated with the development of epistemic responsibility in collaborative learning (Palermos, 2022; Wells, 1999). Such moves were rare in the online class. Students reported that they followed the instructional sequence closely, finding few opportunities to redirect the discussion. This aligns with arguments by Tan et al. (2022), who note that virtual environments can narrow the range of student-initiated reframing.

Patterns of engagement reinforce these differences. Offline discussions encouraged broad involvement, and contributions frequently accumulated into reasoning sequences that built on one another. Howe et al. (2019) identify these cumulative exchanges as important indicators of dialogic progression. In contrast, online discussions often hinged on a small group of confident contributors, while others remained quiet or turned off their cameras. This uneven participation reflects technological and affective challenges documented in the literature and has important implications for how agency can be enacted (Adeoye et al., 2024; Dewantara et al., 2023; Tan et al., 2022).

These patterns matter because agency grows through repeated opportunities to contribute, evaluate, and refine ideas. When such opportunities narrow, learners begin to participate from the edges of the activity. Their roles become more limited, and their contributions less consequential to the direction of the discourse. This process was introduced in the online class, where several students reported feeling less visible or less certain about when to speak (Heikkilä et al., 2023; Nasuwa Mufidah et al., 2025; Yang & Markauskaite, 2023).

Taken together, the findings provide empirical support for the epistemic order framework proposed by Ruthven and Hofmann (2017). The offline class operated within an epistemic order that distributed responsibility for reasoning across participants. The online class displayed a different pattern, one where interaction gravitated more heavily toward the instructor. Epistemic orders shift in response to contextual affordances, and this study illustrates how modality can reshape these structures in practice (Doo et al., 2020; Engeness & Nohr, 2020; Tan et al., 2022).

Bringing the quantitative and qualitative results into conversation with one another clarifies how epistemic agency moderated the learning process. Agency emerged not as a static attribute but as a dynamic presence within dialogue, manifested through initiative, appraisal, framing, and engagement. This relational view of agency resonates with current scholarship showing that agency-rich discourse can influence mathematical reasoning and facilitate conceptual transfer (González-Howard & McNeill, 2020; Li & Xue, 2023; Zhou et al., 2025).

The findings also invite reflection on pedagogical design. Offline environments tended to foster more inclusive participation, while online settings magnified differences in agency and

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reduced the visibility of students who were less confident or less accustomed to dialogic involvement. Researchers have noted the need for intentional supports when designing digital environments for dialogic learning. These include structures for collaborative talk, scaffolds for critique, and varied modalities for expressing mathematical reasoning (Engeness & Nohr, 2020; García-Carrión et al., 2020; Rapanta et al., 2021). The results of this study underscore the importance of such supports and suggest that cultivating epistemic agency across modalities may help create learning environments that are more equitable, generative, and responsive to the diverse ways students participate in mathematical inquiry.

IV. CONCLUSION

The findings of this study demonstrate that epistemic agency plays a crucial role in dialogic mathematics teaching, as it influences how students initiate ideas, evaluate peers' reasoning, and contribute to the development of mathematical meaning across both online and offline learning contexts. These results address the research questions by demonstrating that offline environments support stronger mathematical communication, as they provide greater opportunities for spontaneous questioning, peer appraisal, and flexible task framing. In contrast, online contexts yield more constrained participation and uneven engagement. Based on these findings, several practical recommendations can be considered. Mathematics teachers are encouraged to design learning activities that intentionally broaden opportunities for initiative, critical feedback, and collaborative restructuring of tasks, so that students with varying levels of agency can participate meaningfully, particularly in online settings where interaction tends to be fragmented. Teacher educators and professional development providers may incorporate training that models dialogic facilitation techniques and equips instructors with strategies to cultivate equitable participation. School leaders and policymakers may support the integration of hybrid learning designs that combine the immediacy of face-to-face dialogue with the flexibility of digital tools, enabling sustained epistemic engagement across modalities. Future researchers are advised to examine how different technological features or classroom structures can further enhance or inhibit agency. Strengthening attention to epistemic agency across these domains will contribute to mathematics classrooms that are more inclusive, intellectually rich, and responsive to the needs of diverse learners.

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