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From socialization to internalization: tracing knowledge co-construction through sequential discourse interaction acts in high school English learning

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Introduction: Effective knowledge co-construction (KC) leading to deep internalization remains a critical challenge in high school English as a Foreign Language (EFL) instruction. While classroom discourse is central to this process, the specific sequential mechanisms linking teacher-student interactions to knowledge internalization are underexplored. This study aims to: (1) identify distinct patterns of classroom discourse sequences, differentiating high- and low-quality interactions, and (2) elucidate teachers' scaffolding role in language KC within the SECI (Socialization, Externalization, Combination, Internalization) knowledge creation model.

Methods: Employing an explanatory sequential mixed-methods design within a social-cognitive framework, we video-recorded 56 naturally occurring whole-class EFL lessons across three Chinese senior high schools. Generalized Sequential Querier (GSEQ) software was used to identify and quantitatively analyze 369 discourse interaction sequences for sequential patterns. Subsequent qualitative analysis focused on interpreting the scaffolding mechanisms within these sequences.

Results: Analysis revealed distinct sequential patterns: low-quality interactions were characterized by fragmentation during the socialization and externalization phases, while high-quality interactions exhibited a cohesive spiral structure in the combination and internalization phases. Crucially, sequential analysis pinpointed teachers' pivotal scaffolding role via specific discourse acts throughout the SECI process: contextualized inquiries and cognitive conflicts ignited socialization; metacognitive questioning drove externalization; integrative tasks facilitated combination; and structured practice sequences supported internalization.

Discussion: This study elucidates the sequential mechanisms of KC, demonstrating how teacher-guided discourse scaffolding fundamentally transforms classroom interaction into deep language knowledge internalization. The findings provide a concrete, empirically-grounded framework for understanding and improving the micro-dynamics of KC in EFL classrooms,

offering valuable insights for teacher professional development and the design of more effective discourse-based instructional strategies.

KEYWORDS

knowledge co-construction, sequential discourse interaction acts, socialization, internalization, classroom discourse interaction

1 Introduction

Developing deep, internalized English proficiency is a persistent challenge within Chinese senior high school EFL contexts, characterized by large class sizes and significant pressure from standardized examinations. While interactive approaches are recognized as beneficial, traditional teacher-centered discourse often dominates, limiting opportunities for students to actively participate in constructing linguistic knowledge. This practical reality underscores the critical need to understand the specific mechanisms of effective classroom discourse. The essential significance of classroom discourse interaction in language acquisition is robustly affirmed by fundamental sociocultural theory. Higher-order cognitive functions, such as language proficiency, initially emerge within the interpsychological domain (through social interactions) before being internalized into the intrapsychological domain (individual cognition) (Vygotsky, 1978). Learning is thus inherently a social and dialogic process, facilitated within the Zone of Proximal Development (ZPD) through interaction with more knowledgeable others. This perspective positions learners as active participants, where knowledge is co-constructed collaboratively built through interactive dialogue, scaffolding, and collective reasoning (Thorne and Lantolf, 2006; Swain, 2006; Mercer, 2013; van Lier, 2004). Frameworks like Nonaka's SECI model further conceptualize knowledge creation as iterative cycles: Socialization (building shared tacit understanding), Externalization (articulating tacit knowledge into explicit forms), Combination (systematizing explicit knowledge), and Internalization (embodying explicit knowledge as personal tacit skill) (Nonaka and Takeuchi, 1995). Teacher-student discourse acts are central to driving these transformations.

However, despite this strong theoretical foundation and widespread recognition of interaction's importance, a significant empirical gap remains. Current studies on classroom interaction and KC in language learning often focus on macro-level patterns, such as the prevalent Initiation-Response-Feedback/Evaluation (IRF/E) exchange (Walsh, 2011), or investigate co-construction as a holistic outcome. Crucially, there is a fundamental empirical gap characterized by a lack of research that systematically traces the detailed, moment-by-moment sequences of discourse interaction acts (SDIA—the specific, connected chains of utterances like teacher question→ student response → peer input→ teacher feedback) across the entire SECI process (Socialization → Externalization → Combination → Internalization) within authentic high school EFL lessons (Markee, 2015; Sert and Jacknick, 2015; Jakonen and Morton, 2015). Consequently, establishing a clear empirical link between these micro-level interactional sequences and the subsequent cognitive internalization of knowledge by learners remains challenging. This gap is particularly salient in the context of Chinese senior high school EFL, where understanding the precise dynamics of effective discourse sequences is vital yet underexplored.

This study, therefore, aims to bridge this gap by investigating the intricate processes of KC in Chinese senior high school English classrooms through sequential analysis of discourse interaction acts (SDIA). Specifically, it seeks to: (1) identify and characterize distinct patterns of classroom discourse sequences, differentiating between interactions associated with high- and low-quality KC and (2) elucidate the scaffolding role of teacher discourse moves in facilitating the progression of language KC through the SECI phases (Socialization→ Externalization→ Combination→ Internalization). By meticulously mapping sequences of discourse acts onto the SECI framework, this research seeks to provide a granular understanding of how specific interaction patterns dynamically foster shared understanding and its transition into deep cognitive internalization. Practically, the findings will offer high school English educators evidence-based insights for designing and facilitating more effective discourse interactions. Identifying potent sequential patterns can inform pedagogical strategies, task design, and teacher scaffolding techniques (Walsh, 2011; Soysal, 2023), ultimately enhancing English language proficiency by strategically leveraging interaction to bridge collaborative knowledge building and individual cognitive ownership.

2 Literature review

2.1 Theoretical foundations of KC in language learning

Learning is fundamentally a social and dialogic process. Sociocultural theory, pioneered by Vygotsky (1978), posits that higher cognitive functions, such as language proficiency, originate in the interpsychological domain (through social interactions) before being internalized into the intrapsychological domain (individual cognition). This development occurs within the ZPD, facilitated by interaction with more knowledgeable others using cultural tools, primarily language. Consequently, learners are reconceptualized not as passive recipients but as active participants in constructing understanding (Thorne and Lantolf, 2006; Swain, 2006). Classroom discourse serves as the primary mechanism for this mediation (supportive guidance using tools like language), enabling "collective thinking" (Mercer, 2004) and forming the bedrock for knowledge development within specific socio-cultural and historical contexts (Wells, 1999; Van Lier, 2014).

Building upon sociocultural principles, KC (Knowledge Co-construction) is defined as the collaborative process through which learners jointly build understanding by integrating new information, experiences, and perspectives through dialogue, negotiation, and collective reasoning (Scardamalia and Bereiter, 1994; Roschelle and Clancey, 1992; Mercer, 2013; van Lier, 2004). Dialogue-based negotiation is the key social mechanism driving this process (Mercer, 1995; Baker, 1999), reflecting the depth of knowledge development. KC emphasizes learner agency within a community, where participants actively engage in formulating questions, interpreting information, and collaboratively expanding knowledge, akin to participating in authentic knowledge creation communities (Bereiter and Scardamalia, 2006). This positions KC as a distinct "third metaphor" for learning, centered on collaborative idea improvement (Paavola et al., 2004).

Nonaka's (1994) SECI model posits that KC, particularly for a target language, occurs through iterative cycles of knowledge transformation: Socialization, Externalization, Combination, and Internalization. Classroom discourse facilitates this process through teacher and peer interaction, enhancing linguistic knowledge and transforming cognitive frameworks (Nonaka and Takeuchi, 1995). Socialization involves learners building tacit understanding of target knowledge through shared experiences, observation, imitation, and exposure to diverse perspectives in teacher-learner discourse. Externalization occurs as teachers help students transform tacit knowledge into explicit representations within contextualized activities (e.g., role-playing, text analysis). This enables learners to apply linguistic knowledge to communicative challenges, bridging the gap between theoretical understanding and practical application (Swain, 2000). Combination refers to teachers integrating new explicit knowledge into students' pre-existing cognitive structures. This is achieved by creating authentic topic scenarios and discourse tasks, stimulating engagement and fostering a systematic linguistic knowledge base (Nonaka, 1994; Lantolf, 2000). Internalization is the process where learners convert explicit knowledge into practical skills through independent practice, including experimenting, problem-solving, and refining abilities in new discourse contexts (Swain, 2000).Teacher-student discourse acts are the engine driving these transformations throughout the SECI process (Nonaka and Von Krogh, 2009). These theoretical perspectives collectively establish discourse interaction as the fundamental mechanism for transforming social knowledge into individual cognitive gains, framed by the iterative SECI process. However, analyzing the micro-dynamics of this process—how specific sequences of talk function moment-by-moment—requires dedicated methodological tools.

2.2 Analyzing the micro-dynamics: SDIA

SDIA refers to a series of chronologically, structurally, and functionally interconnected discourse behaviors emerging from teacher-student and student-student interactions during classroom teaching (Mercer, 2004). The primary objective of SDIA analysis is to elucidate the dynamic principles and pedagogical logic of classroom discourse through micro-analysis. SDIA focuses on the sequential organization of turn-taking, emphasizing the relatedness of adjacency pairs (closely linked utterance pairs like question-answer, Sacks et al., 1974) and their logical coherence within extended sequences (e.g., Teacher Question → Student Response → Peer Scaffolding → Teacher Reformulation → Joint Confirmation). Furthermore, SDIA examines the integration of behaviors within specific classroom discourse events, analyzing behavioral trajectories and patterns to reveal the complexity and dynamism of interactions (Sinclair and Coulthard, 2013).

SDIA analysis provides the crucial methodological lens for operationalizing the study of KC and the SECI process at the micro-level. By tracing sequences of utterances, researchers can identify how specific teacher scaffolding moves (temporary, adaptive support, Wood et al., 1976; van Lier, 2004)—such as contextualized inquiries, metacognitive prompts, integrative task instructions, or structured practice sequences—are embedded within discourse flows. This allows for the empirical investigation of how these sequential interaction patterns dynamically facilitate the transitions between SECI phases: igniting Socialization, driving Externalization, enabling Combination, and supporting Internalization. SDIA thus reveals the tangible mechanisms through which discourse scaffolds co-construction and bridges the gap between collaborative knowledge building and individual internalization. Equipped with the theoretical lens of Sociocultural Theory, KC, SECI, and the methodological approach of SDIA analysis, we now examine what empirical research reveals about how KC unfolds through discourse in language learning environments.

2.3 Empirical insights into KC through classroom discourse

Empirical research consistently highlights that the quality of KC is profoundly shaped by the patterns of classroom discourse sequences. The prevalent IRF/E structure has been widely criticized for its teacher-centricity and tendency to limit student autonomy and deeper cognitive engagement, potentially hindering transformative KC (Walsh, 2011; Atwood et al., 2010; Gutiérrez et al., 1995). In contrast, more open-ended, divergent, and dialogic interaction sequences foster deeper comprehension and collaborative meaning-making. Studies emphasize the significance of "exploratory talk" (Mercer, 2008; Schuh, 2003), characterized by reasoning, elaboration, constructive challenge, and responsive engagement, which is strongly correlated with high-quality KC and conceptual development (O'Neill et al., 2013; Orsolini and Pontecorvo, 1992). Rahayu et al. (2020) and Song et al. (2023) further link specific, more complex sequential patterns to advanced KC, especially in secondary education contexts.

Teacher scaffolding and meta-cognitive discourse (meta-discourse) are identified as critical facilitators of deep KC aligned with SECI processes. Research demonstrates that intentional instructional approaches, including skilled facilitation (Hmelo-Silver et al., 2008), structured scaffolding (Nachowitz, 2018), and thoughtful teacher-led coordination focusing on content, engagement, and context (Murphy et al., 2020), are essential for guiding effective discourse sequences. Crucially, meta-discourse, talk about the thinking and knowledge-building process itself, plays a vital role. Studies show that structured meta-discourse and

reflective inquiry significantly enhance epistemic understanding, domain knowledge, intrinsic motivation, reflective depth, and the proposal of novel ideas (Zheng et al., 2023; Zhu et al., 2024; Wu et al., 2022). Teacher scaffolding techniques, such as inviting explanations, prompting causal articulation, or suggesting new directions, are instrumental in prompting more sophisticated student discourse moves and epistemic engagement (Li et al., 2024; Zhu and Lin, 2024). These approaches, supported by analytics where applicable, prove effective across diverse learners, empowering even low-achieving students in meta-cognitive inquiry (Yang et al., 2023). Furthermore, creating a supportive environment marked by mutual trust, intrinsic motivation, and a nurturing institutional atmosphere is fundamental for sustaining productive SECI cycles and deep KC through dialogue and inquiry (Baldé et al., 2018; Nonaka and Von Krogh, 2009). Discourse itself acts as the bridge connecting the SECI model to collaborative learning, enabling the conversion of tacit understanding into explicit knowledge and shared community understanding (Scardamalia and Bereiter, 1994; Lipponen, 2000; Lossman and So, 2010; Wierzbicki and Nakamori, 2007).

Methodologically, frameworks like the Educational Dialogue Analysis (EDA) (Hennessy et al., 2016) and reflective portfolio strategies (RPS) (Lei and Chan, 2018) have been developed to systematically code and analyze the complexity of collaborative dialogue and knowledge building moves. Building on these, Yu et al. (2021) proposed a scheme identifying a spiral progression in high-quality discourse (knowledge acquisition → individual expression → interpretation/analysis → synthesis/refinement → transfer /innovation). The sequencing and effectiveness of interactions are also significantly shaped by broader sociocultural and contextual factors. Lin and He (2017) emphasize the importance of accommodating students' everyday language and translanguaging practices, particularly in content and language integrated learning (CLIL) settings. Gillies (2019) advocates for structured collaborative sequences to scaffold critical thinking effectively. These factors underscore the need to con r the specific instructional and cultural context when analyzing discourse for KC. Collectively, this empirical body highlights the critical role of intentional discourse sequencing, skilled scaffolding, meta-cognitive engagement, and supportive environments in fostering transformative KC. However, significant gaps persist when applying these insights specifically to the dynamics of knowledge internalization through sequential discourse acts in high school EFL learning.

2.4 Research gaps and the focus of the present study

Despite the valuable contributions of prior research, the overarching empirical gap identified in the Introduction, manifests in several critical, interrelated limitations concerning the micro-dynamics of KC leading to internalization, specifically within Chinese senior high school EFL: (1) Empirical studies meticulously tracing KC mechanisms through SDIA analysis are scarce within the unique, high-pressure environment of Chinese senior high school EFL. This context, characterized by large class sizes and intense standardized exam demands, significantly shapes interaction opportunities and dynamics, warranting dedicated investigation; (2) Existing research rarely provides detailed, sequential analysis (SDIA) of discourse interactions that dynamically unfold across all four SECI phases (Socialization → Externalization → Combination → Internalization) within authentic, extended classroom lessons. The micro-genesis (i.e., the detailed, moment-to-moment development) of shared understanding and its link to observable internalization throughout this cycle is underexplored; (3) Systematic application of SDIA analysis as the primary method for elucidating the dynamic mechanisms driving KC throughout the SECI cycle, specifically differentiating high- and low-quality interactions, is notably absent; (4) How each SECI phase is instantiated and scaffolded through identifiable patterns of teacher-student discourse interaction sequences remains inadequately defined and empirically mapped.

To address these interconnected gaps, this study employs a mixed-methods approach integrating SDIA within the SECI framework. We meticulously trace and characterize the micro-processes of KC throughout its trajectory toward internalization in authentic Chinese senior high school English classrooms. Specifically, we investigate distinct sequential discourse patterns associated with co-construction quality and elucidate the scaffolding role of teacher discourse moves in facilitating the progression through the SECI phases.

3 Research questions

In order to address the aforementioned gaps, this study seeks to answer two research questions, which are delineated below:

RQ1: What is the current status of the distribution of discourse behaviors and the levels of KC observed in high school EFL classroom interactions?

RQ2: How do sequential discourse interaction patterns in high school English classrooms facilitate KC, demonstrating the transformation process of the SECI model (specifically, the progression from socialization to internalization)?

4 Methodology

4.1 Research design

This study employs an explanatory sequential mixed methods design (Creswell and Clark, 2017), which prioritizes quantitative analysis followed by qualitative interpretation to explain and deepen understanding of the findings. This approach was specifically chosen for its suitability in investigating the temporal dynamics of discourse sequences in classroom interactions. The quantitative phase (lag sequential analysis using GSEQ) systematically identifies significant patterns and pathways of discourse interaction, while the subsequent qualitative phase (in-depth case studies) provides rich contextual insights into the mechanisms underlying KC. This sequential design aligns with our research focus on tracing the progression from socialization to internalization in classroom discourse, as it allows for the identification of statistically significant interaction patterns followed by a nuanced exploration of their educational implications. The explanatory sequential design was preferred

over other types (e.g., exploratory sequential or parallel) because it leverages the strengths of quantitative analysis to uncover generalizable interaction patterns, which are then elaborated upon through qualitative interpretation, thereby achieving a more comprehensive understanding of the KC process than either method could provide alone. This methodological approach ensures that the study not only identifies what happens in classroom discourse but also explains why and how these interactions facilitate KC.

4.2 Participants and data collection

This study employed convenience sampling to observe and record regular English classes across three senior high schools in City S, a county-level city in Western China, selected for their representation of typical high school contexts in small-sized city within China's educational system. The three schools included one key high school (a prestigious school with a strong reputation for academic excellence), and the other regular high schools. These schools were chosen as they reflect the diversity of English language teaching environments in Chinese senior high schools and provide a suitable context for examining the dynamics of KC in English learning. A total of 42 English teachers participated in the study, and they had diverse teaching experience, ranging from 1 to 30 years, representing a wide range of teaching experience and professional backgrounds. The student participants comprised Grade 10, Grade 11 and Grade 12, with mid-level English proficiency according to the academic requirement of national curriculum criteria. The selection of the three high schools is significant because core-competence orientated English teaching has undergone 3 years rightly. This context provides an ideal setting for examining the transition from socialization to internalization in KC.

The study collected 56 audio/video recordings of regular English classes, encompassing all three senior high school grades and various lesson types (reading, listening, speaking, writing, grammar, and exercise explanation sessions). From these recordings, 369 effective discourse segments were selected as the corpus for analysis, following three rigorous selection criteria: (1) sufficient audio/video clarity for analysis, (2) accuracy in speech-to-text transcription, and (3) the segment constituted a complete interaction event conducted entirely in English. This final criterion was necessary due to the significant portions of class time where instruction occurred primarily in Chinese, which would have complicated the analysis of English-only discourse interactions. What's more, all participants provided informed consent, and the study was approved by Academic Ethics Committee Review Form of Xinjiang Normal University (Approval No. 2023004), ensuring ethical rigor, including participant confidentiality and data anonymity.

4.3 Researcher role and relationship with participants

The primary researchers responsible for data collection, coding, and analysis possess extensive expertise in English language teaching and discourse analysis. The first author has 15 years of experience teaching English at the secondary education level, while the research assistant has 3 years of experience in language instruction. This professional background provided a nuanced understanding of classroom interaction dynamics and the specific pedagogical context of EFL instruction in Chinese senior high schools. However, we explicitly acknowledge that this dual role as both researchers and former teachers constitutes a form of positionality that inherently shapes our perspectives and interpretative processes. Our prior experiences and knowledge frameworks inevitably influenced our understanding of classroom discourse events and subsequent coding procedures.

Access to the research sites (the three high schools in City S) was facilitated through professional networks and institutional contacts. The researchers primarily adopted an observational stance during data collection. While rapport was established with participating teachers through initial meetings explaining the study's purpose and procedures, the researchers refrained from engaging directly in teaching or classroom activities during the recorded sessions. The relationship with student participants was indirect; informed consent was obtained via their teachers and guardians (as detailed in Section 4.2), and researcher contact with students was deliberately minimized to preserve the authenticity of the classroom environment. The primary interaction was through the presence of recording equipment. By explicitly acknowledging our positionality and the nature of our relationship with participants, we aimed to enhance the credibility, dependability, and confirmability of the research findings.

4.4 Coding scheme and procedures

Coding serves as a crucial technique in discourse analysis and represents a fundamental phase in the rationalization and quantification of intricate teaching and learning processes grounded in theoretical frameworks. This process illustrates the researcher's ability to identify, condense, and enhance pertinent information. The development of a coding system is essential to guarantee the scientific rigor, operational clarity, and comparability of research conducted within classroom settings. The present study integrated the SEDA framework developed by Hennessy et al. (2016), the Knowledge Building System proposed by Lei and Chan (2018), the Knowledge Building Discourse Behavior System of Song developed by Yu et al. (2021), as well as Nonaka's (1994) SECI model to measure learners' proficiency in KC. This integration formed the classroom discourse analysis coding system oriented toward KC and its validity was ensured through expert verification and framework dimension alignment before training two coders. Table 1 displays the coding scheme of classroom discourse analysis in KC for this study.

As is shown in Table 1, there are 9 categories in SDIA, including basic knowledge (standardized knowledge, personal knowledge, prior knowledge), individual expression (personal experience, personal imagination, personal opinion), analysis (evaluating, interpreting, expounding), induction (comparing, connecting, summarizing), reasoning and transferring, responding and expanding, recognizing, questioning, and guiding (Yu et al., 2021). "Basic knowledge (BK)" refers to the acquisition of essential

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TABLE 1 The coding scheme of classroom discourse analysis in KC.

Categories	Sub-categories	Description	Exemplar excerpts from classroom discourse interaction events
Basic knowledge (BK)	Standardized knowledge (SK)	Helps learners acquire information, concepts, basics, facts, and learn basic methods and ground rules.	T: What is advice mentioned about how to keep healthy? S: Go to bed in the evening and get up early in the morning.
	Personal knowledge (PK)	Share their acquired knowledge to promote their understanding and mastery.	T: What do you feel getting up in the morning? S: Getting up early makes us energetic a day.
	Review of Prior Knowledge (RPK)	Guide learners to retell prior language knowledge or rules.	T: What tense do we use for completed actions in the past? S: We use the simple past tense, like "She walked to school yesterday."
Individual expression (IE)	Personal experience (PE)	Describe personal experiences and lessons learned to increase learner understanding.	T: What do you usually get up in the morning? S: I often get up at 8 o'clock every day.
	Personal imagination (PI)	Express personal opinions through one's imagination.	T: What will you do if you meet such situation next time? S: I will help them without hesitation.
	Personal views (PV)	Lead learners to express their personal thoughts, emotions, opinions and feelings.	T: What do you think about recycling? S: I feel recycling is essential because it reduces waste.
Analysis (AN)	Evaluation (EV)	Invite students to comment on their peers' ideas or statements	T: Do you agree his idea? S: Yes, I think his idea is very practical.
	Interpretation (IN)	Interpret the process by which a concept or thing is implemented so that others can understand it.	T: How would you explain how human come into being? S: It is a long time to evolve from ancient times to now.
	Expound (EX)	Expound the details of a thing or a story.	T: Could you please tell some details on the spot. S: I saw a boy bleeding heavily and begged me for help.
Induction (ID)	Compare (CM)	Compare and make connections to identify the patterns in language and think holistically and comprehensively.	T: Compare the calligraphy of Qin Dynasty with the one in modern times, what are their similarity? S: Their writing has changed a lot, but they are still the same system.
	Connect (CN)	Connect ideas or concepts from peers or the teacher to form a broader understanding.	T: What should we do to protect our cultural relics from this lesson? S: We should do obey the rules and never damage them.
	Summary (SM)	Enable learners generalize their knowledge of language.	T: We've analyzed 3 paragraphs about animal extinction. What is the main problem causing animals' extinction S: It is human's greediness and killings that makes it.
Reasoning and transfer (RT)		Infer the process of problem solving and develop a sense of creativity to enhance problem solving and innovation skills.	T: What should we do to solve this problem? And why? S: We should have the awareness of protecting our earth firstly, because it may make us do it easier.
Recognition (RC)		Respect and recognize learners' discourse behavior.	T: You really did a good. And could you give me more details about it. S: Well, I think we should do from these things.....
Response and expansion (RE)		Enable learners to listen to others, collaborate with others, and enhance self-reflection.	T: He thinks the character was selfish. Sofia, how does his idea connect to your point about this problem? S: Well, maybe. I have different idea.....
Challenge (CH)		Seek argumentation by disputing others' views and expressing their own ideas.	T: He claims Green Gas is always bad. Any counter arguments? S:... but Green Gas can make our crops grow faster, it.....
Guidance (GD)		Provide targeted support and guidance based on learners' progress and cognitive level.	S: A little boy are walking on the street, and found nothing. T: Well, you mean a boy was walking on the street....

language skills and grammatical principles, which is facilitated through inquiries posed by the instructor and responses provided by the students (Sefhedi et al., 2020); "Individual expression (IE)" refers to the process by which educators facilitate students in articulating their personal thoughts, emotions, opinions, and feelings, which enhances their oral fluency and also promotes diversity in language creation; "Analysis (AN)" means that the teacher guides learners to analyze the structure, meaning and linguistic features of the text in depth, helping them to construct a deeper system of linguistic knowledge. "Induction (IN)" means that teachers guide learners to summarize grammar rules and vocabulary collocation patterns, which effectively promotes learners' global thinking and discovers the rules of language knowledge operation; "Reasoning and transferring (RT)" is the teacher guiding learners to apply known language rules in new contexts, to carry out logical reasoning and context transfer, so as to deepen their understanding and use of the language; "Response and Expansion (RE)" is the teacher responding to learners' answers in a timely and targeted manner, and guiding the topic to a deeper level of expansion; "Recognition (RC)" refers to the teacher's respect for learners' discourse behaviors, which can inspire learners to participate in the classroom interactions more actively to promote

TABLE 2 Classification of discourse threads by knowledge advances.

Levels	Description
Socialization (S)	Simple restatement of linguistic knowledge or the words of others, recall and retell linguistic knowledge.
Externalization-low (E-1)	Try to share their understanding of a grammar point, the usage of a word, etc.
Externalization-high (E-2)	Discuss a language point among themselves or between learners and the teacher.
Combination-low (C-1)	Generalize, summarize and integrate the language knowledge acquired into a complete body of knowledge.
Combination-high (C-2)	Try to construct a framework of language knowledge in order to better understand and memorize it
Internalization-low (I-1)	Be able to use this knowledge automatically and unconsciously to communicate in the language.
Internalization-high (I-2)	Integrate the acquired language knowledge with their own cognitive structure to develop their personal language skills.

the depth and breadth of language learning. "Challenge (CH)" refers to the teacher's encouragement of critical discussion through the setting of open-ended questions, which activates the motivation to participate in classroom learning; "Guidance (GD)" refers to the teacher's provision of timely support to learners according to their learning progress and cognitive level during classroom teaching.

According to Nonaka's theory of knowledge creation (the SECI model), learner's KC levels during English classroom discourse interactions can be categorized into four sequential stages: socialization (S), externalization (E), combination (C), and internalization (I). Specifically, within this study, the stages of externalization, combination, and internalization are further subdivided into two distinct sub-levels each (see Table 2). These sub-levels, designated as externalization (E-1, E-2), combination (C-1, C-2), and internalization (I-1, I-2), reflect the depth of learners' linguistic knowledge application within the classroom context.

4.5 Data analysis

The operational process of the analysis was conducted in four sequential phases (see Figure 1), each designed to systematically transform raw classroom discourse into meaningful insights about KC dynamics. This methodological approach ensured both methodological rigor and theoretical coherence in tracing the progression from socialization to internalization in classroom discourse:

4.5.1 Phase 1: data transcription and structured processing

Holographic transcription was employed using speech recognition technology (WPS's recording-to-text tools) to transcribe classroom discourse between teachers and students. This initial transcription generated a raw text corpus capturing the linguistic features of the interaction. Corpus proofreading followed, involving a meticulous comparison of transcribed text with original video or audio recordings to restore exact language used and ensure transcription accuracy. This included verification of linguistic accuracy and correct sequencing of discourse turns (marked by speaker identification and line breaks), confirming the flow of interaction during the classroom event. Interaction structure annotation applied the IRE framework to analyze teacher-student discourse, identifying discourse adjacency pairs within their temporal sequence to build a structured conversational database.

4.5.2 Phase 2: KC oriented coding of discourse behavior

Phase 2 constitutes a critical stage in analyzing classroom discourse interactions, comprising three iterative coding rounds: (1) Coding participant roles: The initial round identifies the functional roles of participants within discourse interactions. Teacher roles include facilitator, scaffolding provider, feedback provider, and knowledge validator. Student roles include knowledge contributor, questioner, collaborator, and reflector (Sinclair and Coulthard, 2013; Walsh, 2011). (2) Coding discourse acts: Informed primarily by the Classroom Discourse Interaction Acts Coding Framework, this round requires coders to iteratively analyze the relationships between teacher-student discourse and KC behaviors. The goal is to identify specific discourse acts linked to KC (e.g., explaining, questioning, elaborating, challenging) (Mercer, 2004). (3) Coding KC levels: The final round analyzes student discourse during teacher interactions to identify four distinct levels of KC (Nonaka and Takeuchi, 1995; adapted for classroom discourse): In socialization, learners demonstrate dependence on teacher or peer guidance for content. Discourse features include frequent use of tentative language (e.g., "maybe," "I think," "perhaps") and seeking confirmation; In externalization, learners begin to articulate and apply linguistic knowledge explicitly presented by the teacher, using it for foundational tasks and simple discussions (e.g., applying a newly taught grammar rule in a structured exercise); In combination, learners integrate knowledge into a more systematic understanding, allowing them to apply linguistic principles more independently and consistently in interaction, though not yet automatically (e.g., using varied vocabulary and structures appropriately across contexts); In internalization, learners demonstrate spontaneous, confident, and accurate application of target knowledge in discourse interaction (e.g., explaining concepts, reasoning, effective knowledge application, posing novel and relevant questions, and independent, accurate use in new tasks), and a strong sense of ownership over the language is evident.

This critical phase involved a rigorous coding process conducted by two trained coders following a standardized protocol. Both coders underwent comprehensive training, including: (1) thorough review of theoretical frameworks and coding schemes, (2) practice coding 10 sample discourse segments with immediate feedback, (3) iterative refinement until consensus was reached on coding criteria, and (4) development of a detailed coding manual with 20 illustrative examples for each category. The coding process was conducted in three iterative rounds: (1) Coding participant roles (teacher as facilitator, scaffolding provider, feedback provider, knowledge validator; student as knowledge contributor, questioner, collaborator, reflector), (2) Coding discourse acts based on the

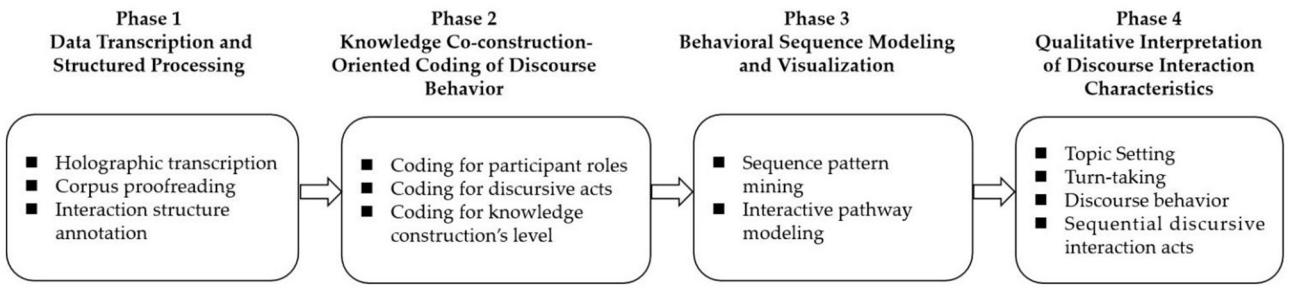

FIGURE 1
The procedures of discourse analysis.

developed coding scheme, and (3) Coding KC levels. Each coder independently coded all 369 discourse segments, with inter-rater reliability calculated after the initial 50 segments. Following resolution of discrepancies through discussion, the remaining segments were coded in parallel. A second round of coding was conducted for segments with low agreement, resulting in final agreement on all segments. Inter-rater reliability was calculated using Cohen's Kappa ($\kappa = 0.82$, $p < 0.001$), indicating good agreement across all coding categories.

4.5.3 Phase 3: behavioral sequence modeling and visualization

During this phase, the analytical method of sequence pattern mining is utilized to construct sequences of behavioral categories related to classroom interactions, aiming to identify patterns within the dynamics of these interactions. Sequence pattern mining serves as a methodology for identifying frequently occurring sub-sequences from a diverse array of sequences. The sequence data encompasses the discourse interactions that transpire between teachers and students throughout the teaching and learning process in the classroom. The detailed procedure for sequence mining is outlined as follows: (1) Lagged sequence analysis was conducted utilizing GSEQ 5.1, with the computation of adjusted residuals (z-score ≥ 1.96) to discern significant behavioral sequences ($p < 0.01$); (2) Utilizing a graphical tool to create matrices that represent the probabilities of behavioral transfer, developing diagrams that illustrate the pathways of discourse interactions between teachers and students, and depicting common patterns of interaction.

4.5.4 Phase 4: qualitative interpretation of discourse interaction characteristics

In order to analyze the dynamics of classroom interaction, it is essential to consider elements such as topic establishment, turn-taking, discourse behaviors, and the relationship between the SDIA and KC. While depicting the topic setting of discourse interaction, it primarily focuses on the question setting of the initiator of the discourse interaction, paying attention to the efficacy of referential or open-ended questions in responding to or evaluating feedback on the subsequent discourse events, and whether they can provide learners with opportunities to participate in the discourse interaction. Turn-taking primarily emphasizes the acquisition, preservation, and transfer of discourse power among the participants in a conversational interaction, thereby reflecting the social dynamics that exist between the interlocutors. Discourse behaviors mainly explicate the skills and abilities of acting in the discourse interaction between the two discourse subjects, reflecting the discourse skills adopted by the teacher to facilitate the progress of the interactions. What's more, the connection between sequential discourse interaction acts and the process of KC is employed to elucidate the mechanisms underlying KC by detailing the sequences of behaviors involved.

This final phase involved in-depth qualitative analysis to interpret the patterns identified in Phase 3. The analysis focused on four key dimensions: (1) topic establishment, particularly examining the efficacy of referential or open-ended questions in prompting discourse; (2) turn-taking patterns, analyzing the acquisition, preservation, and transfer of discourse power among participants; (3) discourse behaviors, exploring the skills and abilities demonstrated in the interaction; and (4) the connection between sequential discourse interaction acts and the process of KC. For each significant sequence identified in Phase 3, the researchers conducted a detailed case analysis, examining the specific discourse moves, interactional dynamics, and cognitive processes that facilitated transitions between KC levels. This qualitative interpretation provided the necessary contextual depth to explain the "how" and "why" behind the quantitative patterns, thereby revealing the micro-processes of KC embedded within classroom discourse interactions.

5 Findings

This section manly presents the current status of the distribution of discourse behaviors and the levels of KC observed in high school EFL classroom interactions (RQ1), and the sequential discourse interaction patterns and the process of knowledge transformation (RQ2), which are delineated below:

5.1 Distribution of discourse behaviors and KC levels

The descriptive statistics concerning acts of classroom discourse interaction in KC (Table 3) and the levels of KC (Table 4) reveal distinct distribution patterns.

TABLE 3 Descriptive statistics concerning acts of classroom discourse interaction in KC.

Categories		N	%
Basic knowledge (BK)	Standardized knowledge (SK)	137	9.05
	Personal knowledge (PK)	20	1.32
	Review of prior knowledge (RPK)	52	3.44
Individual expression (IE)	Personal experience (PE)	27	1.78
	Personal imagination (PI)	20	1.32
	Personal views (PV)	74	4.89
Analysis (AN)	Evaluation (EV)	166	10.97
	Interpretation (IN)	235	15.53
	Expound (EX)	154	10.18
Induction (ID)	Compare (CM)	30	1.98
	Connect (CN)	43	2.84
	Summary (SM)	98	6.48
Reasoning and transfer (RT)		104	6.87
Recognition (RC)		108	7.14
Response and expansion (RE)		127	8.39
Challenge (CH)		64	4.23
Guidance (GD)		54	3.57

TABLE 4 Descriptive statistics concerning the levels of KC.

Levels of KC	N	%
Socialization (S)	25	6.78%
Externalization-low (E-1)	38	10.30%
Externalization-high (E-2)	49	13.28%
Combination-low (C-1)	42	11.38%
Combination-high (C-2)	41	11.11%
Internalization-low (I-1)	84	22.76%
Internalization-high (I-2)	90	24.39%

Table 3 presents the frequency and percentage of occurrences for each discourse behavior category and its subcategories. Within the Basic knowledge (BK) dimension, Standardized knowledge (SK) occurred most frequently (N = 137, 9.05%), followed by Review of prior knowledge (RPK) (N = 52, 3.44%) and Personal knowledge (PK) (N = 20, 1.32%). In the Individual expression (IE) dimension, Personal views (PV) were the most common (N = 74, 4.89%), while Personal experience (PE) (N = 27, 1.78%) and Personal imagination (PI) (N = 20, 1.32%) occurred less frequently. Analysis (AN) was a prominent dimension overall, with Interpretation (IN) being the single most frequent behavior observed (N = 235, 15.53%), followed by Evaluation (EV) (N = 166, 10.97%) and Expound (EX) (N = 154, 10.18%). Within the Induction (ID) dimension, Summary (SM) was the most frequent subcategory (N = 98, 6.48%), while Compare (CM) (N = 30, 1.98%) and Connect (CN) (N = 43, 2.84%) were observed less often. Reasoning and transfer (RT) occurred 104 times (6.87%), Recognition (RC) 108 times (7.14%), Response and expansion (RE) 127 times (8.39%), Challenge (CH) 64 times (4.23%), and Guidance (GD) 54 times (3.57%).

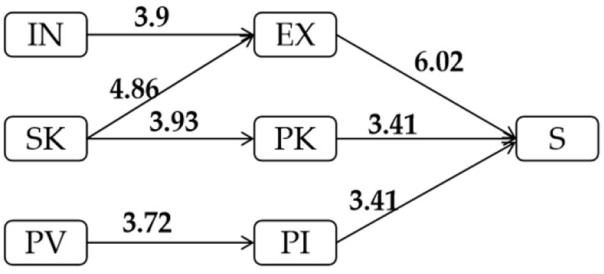

FIGURE 2
Discourse behavior sequence transformation for knowledge socialization.

Table 4 presents the distribution of KC levels. Socialization (S) was the least frequent level (N = 25, 6.78%). Externalization was divided into low (E-1: N = 38, 10.30%) and high (E-2: N = 49, 13.28%) levels. Combination also had low (C-1: N = 42, 11.38%) and high (C-2: N = 41, 11.11%) levels. Internalization was the most frequent level overall, with its low (I-1: N = 84, 22.76%) and high (I-2: N = 90, 24.39%) subcategories showing the highest individual frequencies. The combined proportion for Internalization (I-1 & I-2: 47.15%) was notably higher than that for Externalization (E-1 & E-2: 23.58%) or Combination (C-1 & C-2: 22.49%).

5.2 The sequential discourse interaction patterns and their knowledge transformation

5.2.1 Knowledge socialization: teacher-led transformation pathways

At the Socialization level, knowledge acquisition necessitates learners developing robust conceptual understanding and foundational cognitive schemata. Teachers operationalize this objective through facilitated collaborative recall (lexical/grammatical rules) complemented by strategic questioning to elicit metalinguistic discourse, consolidating linguistic knowledge. Figure 2 models the transformation of epistemic acts through knowledge socialization processes integral to collaborative KC in high school English classroom discourse.

Figure 2 schematizes behavioral sequences from authentic interactions, demonstrating how teacher-guided scaffolding facilitates linguistic KC. This epistemic transformation occurs via four distinct pathways: (1) SK → PK: Teachers provide standardized knowledge (SK), facilitating its internalization and transformation into students' personal knowledge (PK) (Nonaka and Takeuchi, 1995). (2) SK→ EX: Teachers provide SK and scaffold its elaboration through explanatory discourse, leading to students' exposition (EX) of explicit understanding. (3) PV→ PI: Teachers articulate personal views (PV), prompting students to form imaginative cognitions and personal imaginations (PI). (4) IN→ EX: Teachers employ interpretation (IN) to scaffold students to expound (EX)

their ideas through dialogic exchange (Mercer, 2002). The model elucidates the bidirectional dynamics of knowledge socialization: (1) Classroom discourse interactions, mediated by teacher scaffolding, enable students to internalize explicit knowledge. Concurrently, (2) teacher-facilitated guidance catalyzes the transformation of students' tacit knowledge into explicit forms (Nonaka and Takeuchi, 1995). This dual transformation, reinforced by collective negotiation within the classroom community, fosters shared meaning construction. The following excerpts of teacher-guided, learner-constructed knowledge discourse empirically corroborate this mechanism: the following excerpt of teacher-guided discourse empirically illustrates this mechanism:

76	T	Now, let's focus on the body part of the second paragraph.Three steps should be covered. The first one is to list your main sentence. And then, make your sentence longer. And then, try to polish your writing. Polish? Do you know polish?
77	SS	Yeah. To make it better.
78	T	Okay, now, I will show you one sentences to make it longer. For example, Keeping healthy is very important. You can add "I think, I hold the belief that... to the beginning of the sentence, and you... after that, you can give your reasons. Can you try to make this sentence longer?
79	S1	I hold the belief that keeping healthy is very important.
80	T	Very good. You can add one reason.
81	S2	I hold the belief that keeping healthy is very important because if we are healthy enough, we can do what we want.

This sequence exemplifies teacher-led knowledge socialization. The teacher establishes the objective of developing syntactic elaboration strategies (line 76), aligning with explicit strategy instruction (Graham et al., 2012). They then articulate procedural metalanguage (line 78), presenting Myhill et al.'s (2020) three-phase framework: propositional enumeration, strategic elongation, and rhetorical enhancement. Immediately after, the teacher scaffolds understanding by eliciting verification of two specific elaboration techniques: (a) pre-topic embedding using epistemic stance markers (e.g., "I hold the belief that"), and (b) post-topic rationalization via causal explanatory clauses. Student responses (S1/S2) demonstrate initial applications of these techniques to construct extended syntax. This guided interaction facilitated the acquisition of complexification strategies while enabling knowledge socialization through co-constructed linguistic practice (Swain, 2006).

5.2.2 Knowledge externalization: tacit-to-explicit transformation sequences

Knowledge externalization describes the cognitive process of converting tacit knowledge into explicit, codifiable forms communicable through linguistic artifacts. Figure 3 presents the behavioral sequence of knowledge externalization in a high school English classroom, illustrating dynamic pathways mediated by teacher discourse. It distinguishes between primary (E-1) and advanced (E-2) stages.

Figure 3 illustrates the dynamic pathways of knowledge externalization mediated by teacher discourse. Primary externalization (E-1) features four distinct pathways: (1) SK→ PK: Teachers provide standardized knowledge (SK), aiming to enhance students' personal knowledge (PK) through cognitive assimilation (Mayer, 2008). (2) EV→ PV→ AN/SM: Teachers conduct evaluation (EV) to elicit learners to express their personal views (PV), prompting analyses (AN) consistent with cognitive conflict principles (Springer and Borthick, 2007), or followed by structured summary (SM) to foster knowledge integration (Linn, 2000). (3) RT→ CH→ CN: Teachers initiate reasoning and transfer (RT), stimulating challenge (CH) to promote knowledge connection (CN), scaffolding higher-order thinking development. Advanced externalization (E-2) features three distinct pathways: (1) BK→ RPK: Teachers provide basic knowledge (BK), requiring students to review prior knowledge (RPK), leveraging teacher discourse as a sociocultural tool. (2) EX→ RC→ RE: Teachers expound (EX) concepts, prompting recognition (RC) of understanding and leading to response and expansion (RE), embodying dialogic teaching principles (Wells, 1999). (3) EV→ PV: Teachers conduct EV to directly elicit personal views (PV), supporting viewpoint development through inquiry. The subsequent excerpt represents teacher-directed KC:

105	T	.....Now, I would like you to make a dialogue with your desk mate. The first question, you must give the suggestion about how to keep a healthy life. Then, your partner or your desk mate will ask you why you think you should do like this. Have you got the Q and A pattern? Could you two have a try?
106	SS	Yes, state viewpoints and explain our reasons.
107	T	Great, can you two have a try?
108	S1	Could you tell me how to keep a healthy life?
109	S2	I hold the belief that we should go to bed early and get up early.
110	S1	Could you give me your reasons?
111	S2	Because if we do like this, we will become very energetic in daytime.
112	T	Yes, thank you. You two really did a good job.

This peer discourse interaction, initiated by the teacher's task design (line 105), exemplifies knowledge externalization, particularly pathway E-2 (2) EX→ RC→ RE. The teacher firstly expounds the rules of issuing ideas in line 105, and students know the pattern of "stating our viewpoints + reasoning" in line 106. S2's initial suggestion ("go to bed early and get up early," line 109) represents the externalization of tacit personal belief into an explicit proposition (RC). S1's follow-up question ("Could you give me your reasons?", line 108) acts as a peer scaffold, triggering cognitive conflict and prompting S2 to justify his view. S2's response ("Because if we do like this, we will become very energetic in daytime", line 109) constitutes a basic causal explanation (RE- Response and Expansion), further externalizing the tacit rationale behind his initial belief by encoding experiential logic. This dyadic exchange demonstrates the transformation of S2's implicit understanding into progressively more explicit, articulated knowledge through dialogic reciprocity. The teacher's affirmation (line 112) socially validates this co-constructed knowledge. While primarily illustrating externalization (S2's RC and RE), the sequence also touches upon Socialization (T's task setup), Combination (S2 linking action "go to bed early" with outcome "energetic"), and Internalization (reinforced by teacher validation).

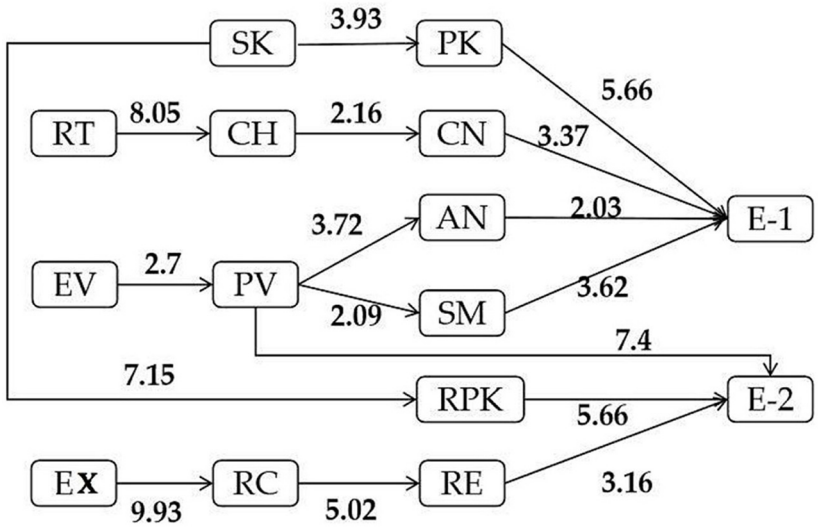

FIGURE 3
Sequential transformation map of discourse behaviors for externalization.

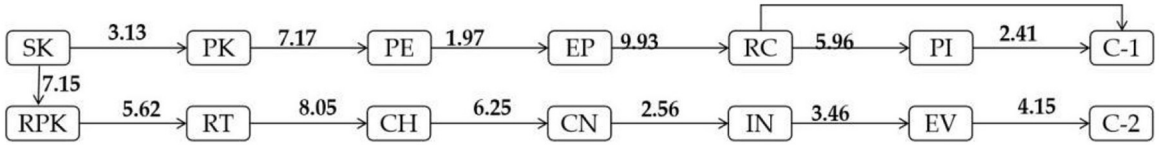

FIGURE 4
Sequential transformation of discourse behaviors for combination.

5.2.3 Knowledge combination: integrated construction pathways

The Combination phase (Nonaka and Takeuchi, 1995) involves systematically organizing and structuring explicit knowledge. It centers on synthesizing disparate linguistic elements into a logically coherent, collectively shared network under teacher guidance. This process deepens individual cognitive understanding and fosters collaborative KC within the classroom community. Figure 4 presents its logic transformation diagram.

Figure 4 illustrates two structured pathways guiding learners toward Combination (C-1, C-2) through teacher-mediated discourse. One is the exogenous integration pathway (SK→ RPK→ RT→ CH→ CN→ IN→ EV). It integrates externally provided knowledge through systematic restructuring. Teachers scaffold this by activating prior knowledge (RPK), prompting reasoning/transfer (RT), encouraging challenges (CH) to build connections (CN), guiding interpretation (IN), and facilitating evaluation (EV) to synthesize into a new structure (C-2). The other is endogenous construction pathway (SK → PK → PE → EP → RC → PI). It constructs knowledge internally by connecting explicit input to personal cognition. Teachers begin with core concepts (BK), link to personal knowledge (PK), draw on experiences (PE), elaborate concepts (EX), elicit recognition (RC), stimulate personal insights (PI), culminating in integrated knowledge (C-1). The following excerpt demonstrates classroom knowledge integration:

89	T	Did you find the topic sentence of this paragraph? The topic sentence?
90	S1	I think the first sentence is the topic sentence.
91	T	Are you sure? Is the first sentence the topic sentence? do you think so?
92	S1	Yes.
93	T	So, you can use one word to summarize the main idea, can you?
94	S2	Effect.
95	T	The effect, do you think so?
96	S2	Yes.
97	T	Yes, very good. Effect. We can see sandstorm affect Beijing. Yes? What's the weather like?
98	S	The weather is an orange sky and strong wind.
99	T	And it's very bad because the sky is full of the thick and brown yellow dust. From the passage we can see, we can see when sandstorm happens, people will wake up to face a dusty sky and the city is covered with thick yellow brown dust. Right? How about the traffic?
100	S	The car can hardly move.
101	T	Why?
102	S	Because it's hard to see because of the brown orange sky and the heavy wind.
103	T	So, we can see the traffic moves slowly just because the dust makes it difficult to see, right?

This excerpt exemplifies the exogenous integration pathway (C-1). The teacher initiates Combination by diagnosing

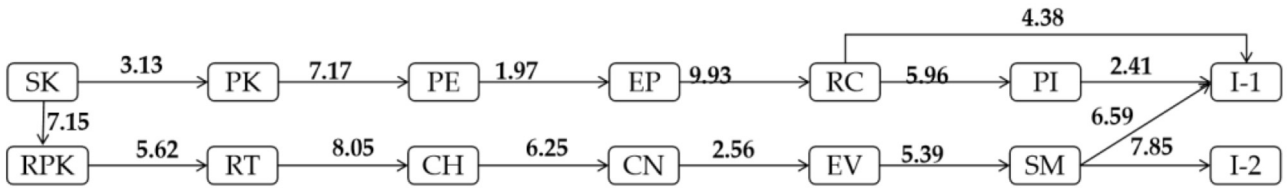

FIGURE 5
Thirty four sequential transformation of discourse behaviors for internalization.

comprehension (RPK) of the topic sentence (lines 89–92, SK→ RPK). S1 and S2's identification and summarization ("Effect", line 94) demonstrate initial comprehension (RPK moving toward CN). The teacher then implements guided questioning (lines 95, 97, 99)—a form of RT (Reasoning/Transfer) and CH (Challenge)—scaffolding students from specific details to analyzing relationships (e.g., dust storm effects → traffic conditions, line 99). This prompts CN (Connection) between environmental and social factors (students' responses, lines 98, 100, 102). The teacher's follow-up "Why?" (line 101) further prompts reasoning (RT), leading S to elaborate (RE - Response & Expansion, line 102). The teacher acts as a "knowledge negotiator", systematically organizing fragmented information (e.g., SK) into a coherent framework through inquiry. This restructuring aligns with Combination's core function. Finally, the teacher's "explain-confirm-expand" move (line 103: "So we can see... right?") (EX → RC → RE) consolidates the causal logic (CN), facilitating social exchange and internalization of the integrated knowledge (C-1). While elements of Externalization (student answers) and Internalization (T's consolidation) are present, the discourse sequence primarily drives the Combination of explicit textual knowledge into a structured understanding of cause-effect relationships.

5.2.4 Knowledge internalization: dual-loop cognitive processing

Internalization denotes the process where learners transform explicit linguistic knowledge into tacit operational competence through scaffolded discourse practice, enabling automatic application. Figure 5 diagrams the sequential discourse transformations driving this process.

Our analysis reveals educators employ a dual-loop process, conceptually analogous to a double helix, intertwining knowledge combination and internalization. While distinct in their specific discourse pathways, both phases fundamentally involve deep knowledge processing and cognitive restructuring. Pathway I-1/2 (e.g., SK→ RPK→ RT→ CH→ RE→ EV→ SM) exemplifies internalization: The teacher anchors in prior knowledge (SK), prompts recall and activates connections (RP, KRT), instigates cognitive conflict (CH), facilitates meaning negotiation (RE, EV), and models/consolidates the cognitive schema (SM). Sub-sequence BK→ RP→ RT aligns with Chi's (2009) active construction theory, operationalizing "receiving-repeating-transferring" for initial grounding. The CH→ RE→ EV sequence embodies cognitive apprenticeship, scaffolding transformation toward tacit competence through dialogic "questioning-responding-evaluating". SM reflects Bransford et al.'s (2005) deep learning focus, using summative discourse to solidify schemas. Unlike the "connection-comparison" focus of combination pathway C-1, the RE→ EV→ SM segment within I-2 specifically drives internalization by negotiating meaning (RE), activating metacognition (EV), and structuring knowledge (SM). The following transcript segment illustrates this internalization process:

132	T	My first question is...., did you see sandstorm before? what's like?
133	S1	The sky was full of sand. All you could see was just yellow and orange. It looked like the sky was coming down. There were no clouds or birds in the sky because they were all flushed down.
134	T	So, what was your first thought when you made the sandstorm scene?
135	S1	Well, I listened to the experts and stayed home. But the wind and sand kept pushing through the cracks in my window. I was scared my house would get covered in sand and I'd lose my things.
136	T	Thank you. What about you? What will you do to solve this situation?
137	S2	What can I do about this problem? The government is already trying to stop desertification by planting trees. I want to volunteer to help plant trees.
138	T	Thank you. Great! In your opinion, in what ways does the sandstorm have an impact on people's daily lives?
139	S2	Well, sandstorms really mess up our lives. When there's a sandstorm, it's super hard to see when you're driving because of all the dust. That makes traffic really bad, and all you hear on the road is cars honking, like "doo-doo-doo" and "beep". You can't ride a bike outside during a sandstorm because the sand can push the bike over. And if you go shopping, you can't use plastic bags. The wind will just blow them away.
140	T	Yeah, thank you. All of you did a good job.

As shown, the teacher facilitates internalization by creating an authentic application scenario through contextualized inquiry (Line 132: "...did you see sandstorm before? what's like?"). This prompts students to apply explicit linguistic knowledge (vocabulary, syntax) to describe (S1, line 133) and analyze (S2, line 139) the sandstorm phenomenon. S1's vivid sensory description (line 133) and S2's solution proposal (line 137) demonstrates initial internalization, moving beyond rote knowledge toward personalized expression and application. S2's summary of impacts (line 139) further illustrates cognitive progression from event recognition to consequence analysis. The teacher's prompt for students' first reaction (line 135) pushes integration of abstract knowledge with personal experience. S2's connection of government action to individual responsibility (lines 137, 139) exemplifies scaffolding: teacher prompts enable

the learner to use explicit knowledge as a framework for deeper reasoning, a step toward internalization. The teacher's immediate feedback (line 140) and the interactive negotiation of meaning support the social validation of emerging understandings, culminating in individual cognitive reorganization and integrated experiential knowledge.

6 Discussion

Building upon the empirical patterns revealed in Section 5, this discussion synthesizes the pedagogical significance of discourse-mediated knowledge transformation in high school EFL classrooms. The observed distribution of KC levels, particularly the prominence of Internalization (47.15%) over Socialization (6.78%), coupled with the sequential pathways of epistemic transformation, illuminates how scaffolded discourse interactions bridge explicit instruction and tacit competence. Drawing on Nonaka and Takeuchi's (1995) knowledge creation theory, we interpret these findings to argue that effective English language learning emerges through three interconnected and progressive aspects: (1) the dominant patterns and constrained dimensions in EFL Classroom KC; (2) the characteristics of high-quality discourse interactions and (3) the KC mechanisms of SDIC. The following sections examine how these aspects resolve the central paradox of L2 pedagogy: transforming declarative knowledge into procedural fluency through classroom discourse.

6.1 Dominant patterns and constrained dimensions in EFL Classroom KC

These observed patterns in discourse behaviors and KC levels warrant interpretation in light of existing theoretical frameworks. The predominance of SK within BK suggests a pedagogical emphasis on transmitting canonical knowledge (Young and Muller, 2010). The relatively low frequencies of PK and RPK indicate limited integration of personalized perspectives and activation of restructured knowledge (Bereiter and Scardamalia, 2014). The pattern in IE, dominated by PV but constrained in PE and PI, points to restricted opportunities for students to draw on experiential or imaginative resources in discourse (Hattan and Alexander, 2020), while aligning with argumentation-focused interaction patterns for views (Asterhan and Schwarz, 2016). The high frequency of AN behaviors, particularly IN and EX, highlights their role as core cognitive mechanisms for knowledge elaboration within collaborative meaning-making (Mercer and Littleton, 2007; Chi and Wylie, 2014). EV also demonstrated significant utility for collaborative judgment. The underutilization of CM and CN within IN suggests these metacognitive regulatory behaviors are less prominent in current co-constructive practices, while the more frequent SM supports knowledge organization (Van de Pol et al., 2010). The presence of RT, RC, and RE indicates their instrumental roles in facilitating knowledge integration, transfer, and collaborative exploration (Bransford and Schwartz, 1999; Asterhan and Schwarz, 2016; Mercer and Howe, 2012). The occurrence of CH signals emerging student epistemic agency through critical interrogation, though its frequency remains moderate. GD functions as contingent scaffolding during co-construction, consistent with dialogic principles, but its frequency suggests a supplementary rather than dominant role in the observed discourse (Van de Pol et al., 2010; Hattan and Alexander, 2020). Collectively, the discourse data reveals an epistemic architecture where canonical knowledge transmission and explanatory elaboration are central. While behaviors supporting consolidation, expansion, and emergent criticality are present, dimensions fostering deep personalization (PK, PE, PI) and higher-order integration/regulation (CM, CN) appear constrained (Bereiter and Scardamalia, 2014).

What's more, the progressive increase in frequency from Socialization to advanced Internalization, culminating in the high proportion of Internalization levels (47.15%), suggests that the observed co-construction processes most frequently culminate in learners integrating co-constructed knowledge into their personal cognitive frameworks (Nonaka and Takeuchi, 1995). The relatively lower representation of Externalization and Combination stages may indicate that articulating tacit knowledge and integrating disparate knowledge sources pose greater challenges, potentially requiring more sustained scaffolding or collaborative effort (Nonaka and Toyama, 2003). This distribution underscores the importance of instructional design not only in facilitating knowledge sharing and combination but also in strategically prioritizing activities that foster deep internalization for profound knowledge assimilation and transformative learning (Moon, 2004).

6.2 High-quality classroom discourse interactions exhibiting a spiral structure

The study reveals that high-quality discourse interactions manifest an iterative, spiraling trajectory of KC, extending beyond the linear progression conceptualized in Nonaka's SECI model. This spiral advancement, however, remains contingent on teachers' deliberate orchestration of cognitive disequilibrium. Specifically, KC is not solely dependent on the instruction provided by the teacher. Instead, it underscores the importance of the learner's engagement within a specific sociocultural context. Yet our data reveal a paradoxical tension: while 82% of socialization /externalization sequences (Table 4) featured teacher-dominated IRE patterns (e.g., Excerpt 76–81), only 37% progressed to higher-order combination/internalization—suggesting most "engagement" remains performative rather than epistemic. This process is facilitated through collaborative interactions with both teachers and fellow learners, enabling individuals to actively construct meaning. As evidenced in combination and internalization sequences (notably Excerpt 132–140 where CH→ RE acts comprised 68% of turns), high-quality classroom discourse interactions can facilitate the construction of cognitive pathways through thoughtfully designed questions that provoke cognitive conflict rather than merely elicit predetermined responses. Such questioning effectively encourages students to engage in independent exploration and problem-solving, thereby fostering higher-order thinking skills. Critically, however, Table 3 shows these metacognitive acts (CM/CN/CH) collectively constituted less than 9% of total

discourse behaviors—exposing a systemic gap between pedagogical intent and implementation.

Moreover, engaging in high-quality classroom discourse interactions has the potential to stimulate students' higher-order cognitive skills, promote deeper thinking, and facilitate comprehensive KC. Conversely—and more prevalently according to our findings—low-quality classroom discourse interactions tend to be disjointed and fragmented. As depicted in socialization and externalization sequences, analysis reveals these interactions are markedly brief, with the lengths of sequential discourse acts shorter than internalization episodes. Within these structures, teachers assume a dominant role (Wells, 1993; Mehan, 1979), while learners' contributions are largely confined to short responses, creating an illusion of participation that actually reinforces knowledge transmission hierarchies. Lower-quality interactions further prioritize foundational linguistic elements, as evidenced by BK/SK acts comprising 74% of socialization turns vs. 12% in internalization (Table 3). Crucially, discourse behaviors explicitly designed to engage learners' metacognitive processes remain significantly underutilized in these contexts (Veenman et al., 2006), notably the near-absence of student-initiated CH (0.7% of acts)—a critical failure in scaffolding cognitive autonomy. Therefore, the language employed by teachers and the questions posed to foster high-quality discourse are not merely products of teachers' spontaneity; they are components of a professional discourse system that adheres to established guidelines. Our data nevertheless expose a fundamental contradiction: despite teachers' procedural awareness (e.g., Excerpt 105-112), institutional assessment pressures often reduce structured discourse to ritualized QA routines that prioritize efficiency over cognitive depth—explaining why only 24.39% of interactions reached I-2 level (Table 4).

The SDIAs from socialization to internalization reveal an evolutionary trajectory characterized by spiraling cognitive frameworks. This spiral, however, frequently stalls at the externalization stage (23.58% occurrence, Table 4) due to teachers' tendency to prioritize closure over contention. In socialization and externalization, teachers emphasize knowledge activation through textbook standardization or "chunking", yet such practices often inadvertently suppress divergent thinking, as shown by PV→ PI transitions occurring in only 8% of socialization sequences. As learners construct lexical-semantic frameworks through teachers' basic knowledge, they establish multidimensional connections that consolidate fragmented rules into generative systems. Critically, however, these systems remain algorithmically rigid (e.g., Excerpt 89–103) when teachers privilege confirmation ("Yes, very good") over intellectual challenge ("What alternative explains this?"). Learners demonstrate proficiency beyond explicit knowledge in combination and internalization phase, engaging in comprehensive analysis and problem-solving. Yet our findings sound a cautionary note: only 11.11% of combination episodes reached C-2 synthesis (Table 4), suggesting most higher-order activities merely simulate depth through procedural compliance. In summary, the progressive phases delineate a comprehensive KC cycle that facilitates spiral cognitive advancement when—and only when—teachers resist premature closure through affirmative, problematizing, and extending strategies. The infrequent observation of combination/internalization discourse (just 34.87% combined occurrence) indicates systemic underdevelopment of higher-order thinking. Thus, while KC quality is indeed measured by profound KC, current classroom practices predominantly reproduce what Bernstein (2003) termed "invisible pedagogies"—ritualized interactions that maintain epistemic authority rather than democratize cognition.

6.3 KC mechanisms of SDIA

While Section 6.2 delineates the observed spiral trajectory of KC and the systemic challenges hindering its full realization (particularly the stagnation at externalization and scarcity of higher-order phases), this section (6.3) delves into the micro-level discursive mechanisms that underpin this spiral structure within the SECI framework. We empirically unpack how specific sequences of SDIA operationalize each SECI phase and collectively drive or fail to drive, the envisioned spiral advancement. Building upon this foundation, we ground our analysis in the theoretical frameworks that illuminate this process. Constructivist theory posits that knowledge acquisition emerges through discourse-mediated co-construction (Vygotsky, 1978), while Nonaka and Takeuchi (1995) provides this with a transformative epistemic cycling through socialization to internalization to understand how knowledge is converted and advanced. Our discourse analysis, visualized in Figure 6, empirically reveals how the micro-level SDIA identified in our data enact and operationalize this SECI framework within the classroom context. Crucially, these phase-specific interaction patterns (also synthesized in Figure 2) collectively scaffold the cognitive progression detailed in Section 5.2 and underpin the spiral trajectory observed in Section 6.2.

Figure 6 synthesizes our findings, mapping the specific sequential discourse interaction acts identified in our analysis (e.g., the pathways detailed in Section 5) onto the SECI knowledge conversion framework. It visually depicts how these micro-level interaction patterns constitute the mechanism driving each stage of KC in the EFL classroom. Socialization constitutes the foundational phase within this SECI cycle (Wertsch and Toma, 2012), providing the essential social context for initiating knowledge sharing and transformation. Teachers play a crucial role in facilitating the development of a shared conceptual understanding by employing targeted discourse interaction strategies. As illustrated in Section 5, teachers utilize strategic questioning (e.g., contextualized inquiries in line 132, Section 5.2.4; designing cognitive conflicts in line 95, Section 5.3) and knowledge exposition (e.g., reiterating prior information in line 78, Section 5.2.1) to structure conceptual knowledge, systematize fundamental methodologies, and organize factual content, thereby establishing common reference points for co-construction.

Externalization, as the critical phase of converting tacit to explicit knowledge (Nonaka and Takeuchi, 1995), is operationalized through deliberately structured dialogic scaffolding (Wells, 1999). Teachers strategically employ metacognitive questioning (e.g., "Why do you think it is important?" in line 80, Section 5.2.1) to surface implicit reasoning, comparative analysis tasks scaffolded

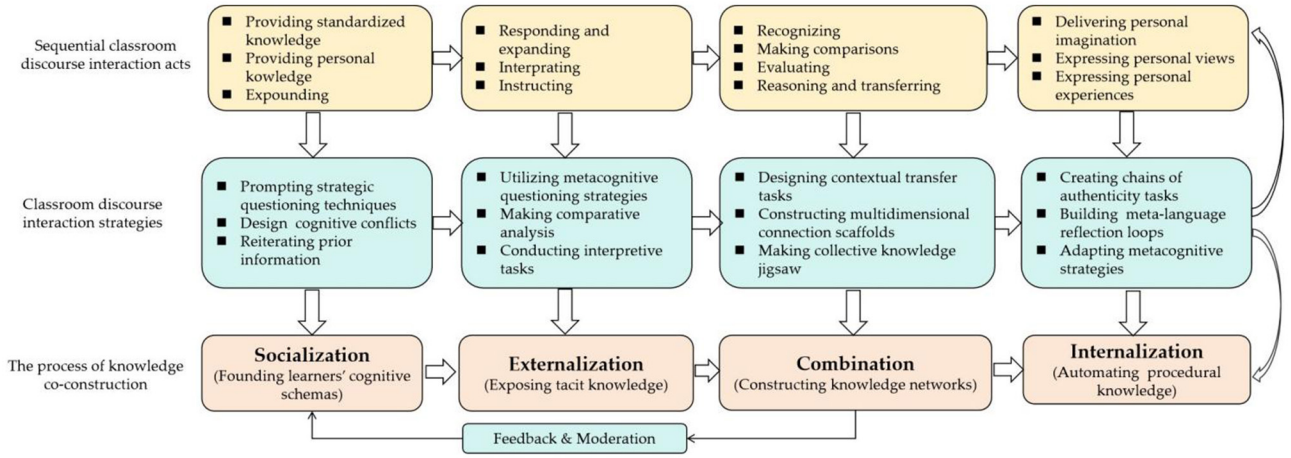

FIGURE 6
Sequential classroom discourse interaction acts and its mechanism of KC.

as exploratory talk (Mercer, 2002) (e.g., "what was your first thought when you made the sandstorm scene?" in line 134, Section 5.2.4), and interpretive scaffolding guiding learners to verbalize procedural knowledge (e.g., elaborating narrative structures in line 78, Section 5.2.1). These discourse acts collectively foster knowledge codification by requiring students to articulate conceptual implementation processes, formulate pattern-based generalizations and synthesize peer/instructor inputs into coherent propositions. Through such co-constructive dialogue, learners transform subjective insights into shareable explicit frameworks, establishing foundations for subsequent knowledge combination.

Combination involves the systematic integration of linguistic knowledge into transferable frameworks. Teachers orchestrate this process through contextualized tasks (Gibbons, 2015), enabling to learners to establish multidimensional conceptual connections, develop cross-situational transfer capacity (Bransford and Schwartz, 1999), and construct effective problem-solving schemata. Specifically, teachers (1) design integrative discourse activities linking linguistic concepts with contextual topics (e.g. "Did you find the topic sentence of this paragraph? The topic sentence?" in line 89, Section 5.2.3), (2) facilitate collaborative synthesis using structured protocols (e.g. "What's the weather like?" in line 97, Section 5.2.3), and (3) guide comparative analysis of linguistic patterns across contexts (e.g. "effect" in line 94–97, Section 5.2.3). These sequential discourse interactions (Mercer, 2013) enable learners to: (1) integrate linguistic knowledge into interconnected cognitive frameworks; (2) exchange and refine perspectives through structured knowledge-building discourse; and (3) internalize principles of transfer via metacognitive reflection on recurring patterns. Ultimately, this process equips learners to identify core principles governing cross-contextual application, demonstrating Combination's role in constructing adaptable knowledge architectures.

Internalization signifies the proceduralization of knowledge through scaffolded practice, transforming explicit understanding into tacit operational competence (Nonaka and Takeuchi, 1995). Teachers facilitate this process by designing authentic discourse tasks that structure an internalization sequence: strategic language execution → metalinguistic reflection → cognitive strategy refinement (Oxford, 2016). Within novel communicative contexts, learners apply target linguistic knowledge through exploratory discourse (e.g., In your opinion, in what ways does the sandstorm have an impact on people's daily lives? In line 138, Section 5.2.4), articulate conceptual understanding (e.g. "The sky was full of sand...." in line 133, Section 4.2.4), identify implementation challenges via experiential analysis (e.g. "But the wind and sand kept pushing through the cracks in my window...." in line 135, Section 5.2.4), and collaboratively co-construct solutions (Mercer, 2013). These interactions foster progressive enhancement of critical thinking and problem-solving capacities. Teachers propel this KC spiral (Nonaka and Von Krogh, 2009) by acknowledging and interrogating student contributions, responding to and enhancing conceptual connections (Gibbons, 2015), providing targeted feedback to enable error identification and calibration (Hattie and Timperley, 2007), and structuring peer assessment protocols to promote self-regulated correction (Topping, 2009). Ultimately, scaffolded discourse interactions complete the SECI knowledge conversion cycle (Nonaka and Takeuchi, 1995), transitioning socialized knowledge into internalized expertise.

Critically, this SECI enactment is configured through three discourse design principles: (1) Teachers deploy cognitively catalytic moves to initiate each SECI conversion with phase-specific triggering mechanisms (Nonaka and Takeuchi, 1995). Failure to deploy such moves effectively, often replaced by closure-seeking IRE patterns under institutional pressures (Section 6.2), directly contributes to stagnation at externalization. Socialization is ignited by the teacher through contextualized inquiries (line 132) to provide the shared experiential context necessary for tacit knowledge sharing (Nonaka and Von Krogh, 2009), and cognitive conflict induction (line 95) to create the psychological impetus for learners to seek resolution through shared sense-making and observation within the group (Doolittle, 1997).

Externalization requires discourse moves that compel articulation and conceptualization by metacognitive questioning to force learners to reflect on their own thinking processes and the underlying logic of their tacit understanding. Combination requires framing integrative task to direct learners toward systematic knowledge restructuring and integration (Nonaka and Takeuchi, 1995; Goh, 2002), requiring connection/comparison of explicit conceptual models. Internalization is facilitated through structured practice sequences, wherein teachers design and articulate sequences of scaffolded application activities and learners can consciously connect the explicit knowledge being practiced to their actions and emerging intuitions. (2) Strategic chaining of discourse acts creates epistemic synergy, as exemplified by pathways (e.g., reasoning → standardized knowledge → personal imagining). The predominance of disjointed, teacher-dominated sequences (Section 6.2, Table 3) starkly contrasts with the synergy generated by strategic chaining. These sequences enable dialectical co-construction through teacher's epistemic guidance and learners' constructive acts. (3) SECI progression demonstrates non-linear recursivity through spiral reinforcement and phase embedding. The systemic underdevelopment of combination/internalization (Section 6.2, Table 4) can be partly attributed to infrequent embedding of recursive sub-cycles. Specifically, internalization re-engages socialization-based experiences (e.g., recalling shared contexts during strategy refinement) and combination tasks incorporate externalization sub-cycles (e.g., re-verbalizing concepts during cross-context transfer in line 139, Section 5.2.4)

This study contributes to the field by empirically delineating the specific sequential discourse patterns that operationalize the SECI model in high school EFL contexts, moving beyond abstract principles to concrete interactional mechanisms. Our findings regarding the "spiral advancement" structure offer a refined understanding of cognitive progression within KC cycles. Furthermore, the identification of prevalent pathways for socialization/externalization vs. the scarcity of those leading to combination/internalization highlights a critical area for pedagogical development. For practitioners seeking to counteract the prevalent issues of performative engagement, premature closure, and underdeveloped higher-order thinking identified in Section 6.2, the detailed pathways (e.g., those effective for externalization or internalization) provide concrete templates for designing discourse interactions. Recognizing the importance of structured sequences that elicit cognitive conflict and negotiation (as in path BK→ RPK→ RT→ CH→ RE→ EV→ SM) can guide teachers in crafting questions and tasks that target higher-order thinking and deep knowledge internalization.

7 Conclusions

7.1 Summary of findings

The present study offers an in-depth analysis of the classroom discourse interaction of 369 communicative acts in conventional EFL classrooms, and draws the following conclusions. (1) Classroom discourse interactions in the observed Chinese high school EFL contexts frequently operate within a "basic knowledge+" framework (Hattan and Alexander, 2020). While consolidating foundational linguistic knowledge serves as a common starting point, the "+" dimension, encompassing strategic interaction configurations intended as dialogic scaffolding, often manifested as teacher-dominated IRE patterns, particularly in socialization and externalization phases (Lyster et al., 2013; Van de Pol et al., 2010). While essential for establishing common ground, this prevalent mode demonstrated limited efficacy in consistently scaffolding the progression toward deeper, student-driven KC involving personalization (PK, PE, PI) and higher-order integration /regulation (EV, CN), as evidenced by the constrained representation of these behaviors and the modest transition rates from lower to higher KC levels (Tomlinson, 2014).

Despite the prevalence of analytical discourse, the observed classrooms revealed a critical deficit in interactions that foster inferential reasoning and knowledge transfer. Specifically, while discourse patterns centered on analysis (IN, EV, EX) were prominently and effectively utilized, constituting the most frequent interaction type, the frequencies and substantive depth of discourse behaviors crucial for these higher-order processes, specifically CM, CN, RT, and particularly student-initiated CH, remained markedly low. This deficit, linked to observed pedagogical tendencies prioritizing closure over cognitive conflict and institutional pressures favoring efficiency over depth, significantly constrained the potential for higher-order comprehension, application, and the attainment of advanced KC levels (Mercer et al., 2009; Webb et al., 2014).

High-quality classroom discourse interactions, when successfully enacted, exhibit a recursive, spiraling trajectory of KC: progressing from foundational knowledge provision → interpretive analysis → synthetic refinement → applicative transfer. This scaffolded sequence, crucially mediated by teacher strategies that deliberately induce cognitive disequilibrium and problematize knowledge (e.g., through probing questions targeting cognitive conflict), operationalizes the theoretical movement from social negotiation to individual cognitive internalization (Mercer, 2002). However, our findings reveal a significant gap, as such interactions culminating in advanced Combination and Internalization levels were observed in only approximately one-third of the sequences, highlighting the challenge of consistently achieving this ideal spiral in practice.

Questioning, particularly initiated through core questions extended by progressive probing (Chin and Osborne, 2010), serves as the primary epistemic engine driving classroom discourse interaction. However, while extended interaction sequences (EIS) hold significant potential, as demonstrated in sequences reaching higher KC levels, the prevalent form of interaction observed was often teacher-dominated IRE patterns within fragmented exchanges. Truly effective EIS, characterized by sustained and dialogic exploration where students engage in deep reasoning, knowledge negotiation, challenge, and personalized application, proved less frequent but demonstrated markedly greater efficacy. These high-quality EIS were critical for scaffolding deeper conceptual understanding, facilitating higher-order cognitive development (Resnick et al., 2010), and enabling integrated KC culminating in advanced Combination and Internalization levels.

7.2 Pedagogical recommendations

Therefore, building upon the aforementioned findings, this study proposes the following actionable recommendations for enhancing KC. Firstly, teachers should establish an open and inclusive classroom climate that actively encourages questioning, initiative-taking, and the exploration of novel ideas and methodologies to cultivate an environment conducive to innovation and the sharing of tacit knowledge. Such an environment serves as a foundational condition for initiating the socialization phase of KC (Nonaka and Von Krogh, 2009). Teachers can further stimulate this process by designing contextualized inquiries and deliberately introducing cognitive conflict, such as strategies observed in classroom interactions (e.g., lines 95, 132), which prompt learners to re-examine assumptions and engage in deeper dialogue. Techniques such as reverse thinking not only foster creative problem-solving but also help construct a shared experiential context and psychological readiness essential for the exchange of tacit knowledge (Doolittle, 1997). Through these approaches, learners are better positioned to unlock their innovative potential and participate meaningfully in collaborative KC.

Additionally, teachers should implement diversified metacognitive strategies to mitigate fragmented and superficial discourse interactions. By extending the depth and breadth of discourse interactions and constructing cognitive scaffolding for knowledge building, it directly addresses the discourse moves required for effective KC, which compels articulation and conceptualization through metacognitive questioning. This approach, moving beyond simple elicitation, more effectively cultivates students' holistic competencies and core literacies by forcing reflection on thinking processes and the logic of tacit understanding. Furthermore, teachers should establish purposeful classroom discourse patterns and design logically sequenced question chains aligned with linguistic knowledge systems and cognitive hierarchies. This scaffolding exemplified by effective pathways like BK → RPK → RT → CH → RE → EV → SM that elicit cognitive conflict and negotiation, is crucial for directing learners toward systematic knowledge restructuring and integration through connection and comparison of explicit conceptual models (as per Nonaka and Takeuchi, 1995; Goh, 2002), and facilitating deep knowledge assimilation via structured practice sequences of scaffolded application activities. More importantly, leverage the non-linear recursivity of SECI by designing tasks that intentionally recall prior shared contexts or require re-verbalization during new applications (e.g., cross-context transfer as in line 139). This strategic discourse design can guide learners toward progressively deeper understanding, ensuring the internalization of linguistic knowledge and fostering higher-order cognitive development.

7.3 Limitations and future research

This study offers a detailed insight into KC within Chinese high school English as a EFL classrooms; however, several limitations warrant consideration. First, the results are predominantly based on the analysis of verbal interactions situated within a particular exam-focused educational environment. Consequently, the applicability of the proposed "basic knowledge+" model and its associated challenges to other educational contexts, such as junior middle schools, may be restricted. Second, the reliance on a predetermined coding scheme, although enhancing analytical rigor, may have limited the detection of additional emergent, culturally specific interactional patterns that fall outside the scope of the current framework. Lastly, as a cross-sectional investigation, the study provides a comprehensive snapshot of classroom discourse but does not capture the longitudinal developmental effects of specific discourse patterns on students' cognitive development and language acquisition.

Building upon the current findings and acknowledged limitations, subsequent research endeavors might (1) design and assess instructional strategies specifically targeted at promoting the underrepresented discourse moves (e.g., CH, CN) identified within this investigation; (2) employ longitudinal methodologies to investigate the impact of teacher scaffolding during the initial phases of knowledge construction on students' subsequent ability to internalize content independently; and (3) explore the interplay between the demands of standardized testing and educators' propensity to participate in more open-ended, time-intensive dialogic interactions.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving humans were approved by Academic Ethics Committee Review Form, School of Psychology, Xinjiang Normal University. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin.

Author contributions

YW: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft, Writing – review & editing. MK: Project administration, Supervision, Validation, Writing – review & editing. GO: Funding acquisition, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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