

Ambiguity-Driven Guidance: How Designing for Productive Confusion Reactivates Teacher Value

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Abstract

The rise of generative AI redefines educational technology's design space, yet most systems follow "prompt-to-output" efficiency logic, overlooking teaching's essence—guiding rather than providing answers. This study proposes "ambiguity-driven guidance" as a novel design principle, with technical implementation including: (1) dynamic concept clouds based on BGE-M3 and graph attention networks supporting open-ended semantic construction; (2) genre-specific semantic expansion logic matching different writing tasks' cognitive demands; (3) progressive clarification interfaces simulating expert teachers' heuristic questioning styles. In a 5-week longitudinal study, 18 pre-service language teachers experienced significant identity transformation: from authoritative knowledge transmitters to heuristic thinking facilitators. System logs show users shifting from "seeking correct answers" to "embracing exploration processes," averaging 122.8 concept-path construction steps per task. Qualitative interviews reveal a three-layer transformation mechanism: ambiguity first creates cognitive tension, exploratory behaviors serve as mediating processes, and sustained engagement ultimately leads to systematic professional identity reconstruction.

Introduction

When ChatGPT can generate a structurally coherent essay in seconds, language teachers find themselves facing unprecedented disruption. The reason lies in the epistemic philosophy of current AI tools: they are optimized to deliver outputs rather than to represent learning processes. This shift unintentionally recasts teachers from facilitators of cognition into mere spectators of student outcomes. Recent survey data from 1,200 educators shows that 81% perceive AI tools as a professional threat, and 76% believe that students' over-reliance on automated writing weakens their critical thinking abilities (Davis et al., 2024).

The root cause is not only technological capability, but interaction design. Popular systems like ChatGPT and Claude rely on direct "prompt-to-output" mappings, while revision-oriented tools such as Grammarly or ProWritingAid provide instant corrections. Although efficient, these paradigms strip users of agency in cognitive exploration. Recent research has attempted to mitigate this issue, for instance by adding explanatory features to improve interpretability (Lee et al.,

2024) or generating multiple drafts for user choice (Hollestein et al., 2019). Yet such interventions remain bound by a one-way logic: the system provides, the user receives. What remains underexplored is how AI can act as a catalyst for thought rather than a surrogate for it.

To address this gap, we introduce an interaction paradigm of "ambiguity-driven guidance." Instead of providing direct answers, our system leverages a graph attention network (GAT) to dynamically expand semantic associations, constructing a controllable concept network that situates learners in a state of "productive confusion." A dual-platform architecture anchors this design: one end identifies the learner's cognitive starting point, while the other visualizes an exploration space, ensuring that users retain epistemic agency throughout.

Our contributions are threefold:

1. **Interaction innovation** — operationalizing the pedagogical principle of productive ambiguity as a design principle for HCI.
2. **Technical breakthrough** — applying GAT to educational interaction, addressing the limitations of similarity-based algorithms in heuristic contexts.
3. **User experience redefinition** — shifting focus from task completion to cognitive engagement, rebalancing automation and human agency.

Through a five-week longitudinal study with 18 pre-service language teachers, we demonstrate that ambiguity-driven guidance significantly reshapes professional identity: traditional authority beliefs declined (Cohen's $d = -1.65$), preference for heuristic teaching increased ($d = 1.17$), and AI-related anxiety decreased ($d = 0.54$). Behavioral data further reveal deep cognitive investment: participants averaged 39.9 exploratory clicks, built 122.8 concept-path steps, and engaged for 9.8 focused minutes per session. Crucially, exploration intensity strongly correlated with pedagogical transformation ($r = 0.65, p < 0.01$), reinforcing the value of AI as a scaffold for guided inquiry.

Ultimately, our study challenges the zero-sum assumption that "AI inevitably diminishes the value of teachers." When designed as a catalyst for thinking, AI can convert professional threats into opportunities for growth. Preserving and amplifying human cognitive agency—especially the irreplaceable role of teachers as facilitators of thought—is

the central challenge that motivates this work.

Background

From Authority to Crisis

For much of modern writing pedagogy, the professional authority of teachers has rested on epistemic asymmetry: they possessed the strategies, exemplars, and evaluative standards that students lacked, positioning themselves as both “model writers” and “evaluators” (Beijaard et al., 2004; Lortie, 1975). This asymmetry functioned not only as a pedagogical structure but also as the foundation of teachers’ professional identity.

The rise of generative AI tools such as ChatGPT, Grammarly, and Notion AI, however, has begun to destabilize this foundation. Writing has increasingly shifted from a process of idea construction to a task of language generation. Students can bypass planning, exploration, and revision to instantly obtain grammatically correct and structurally coherent texts. This shift compresses the learning trajectory and redistributes epistemic authority. Teachers, no longer the sole gatekeepers of knowledge, find themselves displaced to the margins of the cognitive process, experiencing uncertainty and identity anxiety (Giddens, 1991).

Importantly, this displacement is not merely a byproduct of technological capability but a consequence of system design. Current AI writing systems are predominantly optimized for output efficiency and individual user experience. They provide students with polished text but rarely afford teachers mechanisms to guide, mediate, or even observe the underlying process (Lee et al., 2024). Teachers are often positioned as external evaluators—visible only at the end of the workflow—rather than as active collaborators in meaning-making. Such structural exclusion renders teachers simultaneously “invisible” and “inactionable,” eroding their professional agency in the classroom (Amershi et al., 2019).

This raises a critical challenge for HCI and educational technology design: empowering teachers is not simply a matter of adding interfaces but of rethinking role modeling within AI systems. If writing support tools are to genuinely serve pedagogical goals, teachers must be repositioned from after-the-fact assessors to facilitators of thought and co-designers of the writing process. This reframing demands system capabilities such as teacher-adjustable scaffolds, process visualizations, and mechanisms for sustaining cognitive tension. The following section builds on this challenge by examining ambiguity and scaffolding as theoretical foundations for such a redesign.

Scaffolding Through Ambiguity

Educational theory has long emphasized that effective teaching is not the transmission of answers but the orchestration of inquiry. Vygotsky’s concept of the Zone of Proximal Development (ZPD) highlights that learning is most productive in the space between what a learner can do alone and what they can achieve with guidance (Vygotsky, 1978). Within this zone, scaffolding serves as adaptive, temporary support that enables learners to extend their capabilities beyond independent performance (Lajoie, 2005).

Yet scaffolding is rarely a matter of providing clarity alone. Research in the learning sciences demonstrates that productive ambiguity—strategically introducing uncertainty or partial information—can foster deeper engagement. Bruner (1966) show that ambiguity, when used intentionally, creates cognitive tension that provokes exploration, reflection, and sense-making. This principle resonates with the framework of desirable difficulties in cognitive psychology, which argues that moderate challenges, such as uncertainty or delayed resolution, enhance long-term retention and transfer precisely because they demand greater cognitive effort (Bjork & Bjork, 2011).

Classic pedagogical practices such as the Socratic method exemplify this principle. Instead of supplying solutions, teachers continually probe with “why,” “what if,” or “how else,” pushing learners to articulate, defend, and revise their reasoning. Here, ambiguity is not instructional failure but an epistemic resource—a means of cultivating agency and intellectual resilience.

In recent years, these insights have informed computational learning environments. Educational technologies increasingly embed metacognitive prompts, reflective triggers, and elaboration scaffolds—not to deliver knowledge, but to elicit it (Azevedo & Aleven, 2013). By asking learners to justify claims, surface contradictions, or consider alternatives, systems sustain a state of productive uncertainty. In doing so, they preserve the very cognitive struggles that drive higher-order thinking.

For writing in particular, this perspective is crucial. Writing is not merely linguistic output but a mode of thinking and identity formation (Emig, 1977). Systems that overemphasize fluency or completeness risk short-circuiting the reflective processes that make writing pedagogically valuable. Instead, AI writing support should be reimaged as a partner in ambiguity—offering heuristic prompts that sustain exploration rather than finalize answers. Designing for such scaffolding reframes AI not as a replacement for cognition, but as a collaborator in cultivating it.

Beyond Generation: Creative Writing

Existing AI writing tools largely follow a product-oriented logic, optimizing for textual efficiency and surface fluency through functions such as auto-completion, grammar correction, and style imitation (Lee et al., 2022). While these affordances reduce friction, they often conflict with learning goals. Immediate fluency can discourage revision, pre-generated exemplars may narrow originality, and automated suggestions risk prematurely constraining exploration and reflection (Holstein et al., 2019; Kasneci et al., 2023). In practice, generative AI frequently acts as a substitute rather than a collaborator—providing answers when learners need questions, and producing results when teachers aim to guide processes.

This tension has prompted a critical question: should writing support systems shift from generative AI toward heuristic or facilitative AI? The latter emphasizes ambiguity, openness, and reflective prompts to deepen thinking under conditions of uncertainty (Bjork & Bjork, 2011). Early attempts in this direction include interactive writing assistants that scaf-

fold ideation through heuristic prompts (Lee et al., 2024) and educational technologies that embed metacognitive supports (Azevedo & Aleven, 2013). Yet these efforts remain limited in scope, and few studies have investigated how such facilitative mechanisms can be translated into teacher-facing tools that amplify instructional practice.

Creative writing offers a particularly fertile testbed for this exploration. Unlike academic writing, which prioritizes structure and convention, creative writing relies on divergent thinking, emotional resonance, and narrative imagination (Sawyer, 2011). It is not only a form of expression but also a process of cognitive construction and identity formation (Emig, 1977; Kaufman & Beghetto, 2009). These qualities expose the shortcomings of generative systems: while capable of producing grammatically correct text, they struggle to deliver contextualized creativity or authentic voice. Students risk receiving polished but hollow outputs, losing opportunities to wrestle with ambiguity and cultivate originality or critique. At the same time, teachers' comparative strengths—asking probing questions, fostering reflection, and situating ideas in meaningful contexts—remain under-supported.

Seen in this light, creative writing not only reveals the limitations of generative AI but also underscores the potential of heuristic AI. By providing exploratory spaces and dynamic scaffolds rather than final products, systems can serve as cognitive partners rather than competitors. This orientation is particularly consequential for pre-service teachers and community educators. Situated in transitional phases of professional identity, they must learn how to guide others' thinking even as they refine their own. If overexposed to product-oriented AI, they risk internalizing a role as "replaceable answer providers" rather than "facilitators of thought." Conversely, when trained in heuristic modes of engagement through creative writing, they may diffuse these practices into their future classrooms, amplifying not only innovation in pedagogy but also broader commitments to equity in education.

Educators-in-Transition

Within the broader educational landscape, pre-service teachers represent a transitional identity that is both distinctive and underexamined. They simultaneously inhabit a dual role: as learners refining their own cognitive and pedagogical skills, and as future educators expected to shape others' learning. Many of them, particularly in under-resourced contexts, are also likely to take on the responsibilities of community educators after graduation. This dual positioning makes them uniquely sensitive to the affordances and risks of AI writing tools, while also amplifying their potential multiplier effect within the education system.

From a developmental perspective, teacher preparation is not merely about acquiring knowledge and skills, but about constructing a professional identity (Beauchamp & Thomas, 2009). Research shows that creative and narrative practices support pre-service teachers in reflecting on their educational beliefs, cultivating empathy, and strengthening instructional confidence (Clough, 2010; Sawyer, 2011). In this process, writing functions not only as a medium of expression but also as a site for imagining and negotiating profes-

sional roles. Thus, the role of AI in writing support extends beyond text generation; it implicates how teachers come to understand, enact, and sustain their practice.

At the systems level, this group also represents a critical leverage point for educational equity and sustainability. Pre-service and community educators often work in resource-constrained environments, with limited access to mentoring or adaptive tools. Yet their teaching practices frequently diffuse across classrooms and communities, producing large-scale ripple effects (Darling-Hammond, 2010). Designing AI tools that empower them during this formative stage therefore carries the potential for disproportionate impact: supporting not only individual growth, but also the educational opportunities of future students.

Equally important, pre-service teachers provide HCI research with a rare observational window. Unlike in-service teachers whose identities are relatively stabilized, educators-in-transition continuously negotiate their professional positioning. Their interactions with AI tools expose these negotiations in real time, revealing how technology can disrupt, reinforce, or reconfigure the epistemic basis of teaching. Such empirical insights remain scarce but are crucial for understanding how generative AI shapes both teacher identity and classroom practice.

In summary, pre-service teachers and community educators are not merely end users of AI writing systems; they are critical test cases for examining how generative AI can shift from being a text generator to becoming a cognitive collaborator. By focusing on this population, we not only illuminate the dynamic process of identity transformation under AI integration but also trace how these transformations may diffuse into broader educational ecologies—ultimately advancing both educational equity and the reconfiguration of human-AI collaboration in pedagogy.

Method

Research Motivation and Theoretical Grounding

The art of teaching often lies in subtle guidance. When students ask about writing techniques, experienced teachers are more likely to respond with questions such as: "What's the most memorable piece you've read, and why did it move you?" This type of fuzzy guidance reveals the unique value of human educators—not in delivering answers, but in stimulating reflection and meaning-making. In contrast, most current AI-powered educational systems prioritize precision and correctness, overlooking the productive role of ambiguity in learning. This study explores how fuzzy guidance can be embedded into AI systems and how such human-AI collaboration affects the professional identity formation of pre-service teachers.

We adopt a four-stage longitudinal design—pre-test → AI interaction → system use → post-interviews—to track the dynamic process of identity transformation. A mixed-methods approach is used to capture both the quantifiable shifts in cognitive structure and the experiential, qualitative aspects of identity change. We focus on Chinese pre-service language teachers who are in a critical transition from learners to educators. Their cognitive frameworks remain flexi-

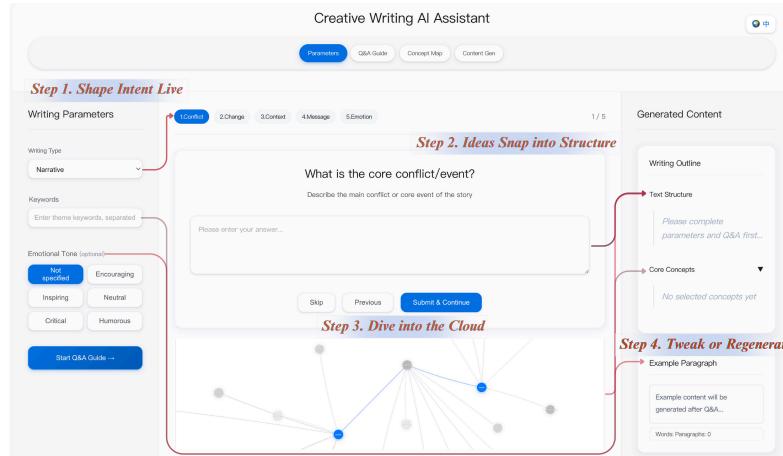


Figure 1: Fuzzy guidance system interface design.

ble, yet they possess professional sensitivity to pedagogical approaches. We select creative writing instruction as the target context, given its high demand for emotional resonance and personalized guidance—qualities that human teachers excel at, and that remain difficult for AI to replicate.

Theoretically, this research contributes an operationalized definition of fuzzy guidance and proposes a technical implementation pathway. Practically, it offers a novel design lens for transforming teacher education in the age of AI.

Participants

We recruited 18 pre-service Chinese language teachers as participants. This population was chosen for its dual-role identity: they are both learners and prospective educators, making them ideal for studying shifts in professional identity under the influence of AI-supported instructional experiences.

Participants were enrolled in or recently graduated from a teacher education university in southern China. Their ages ranged from 21 to 24 ($M = 22.2$, $SD = 2.1$), including 3 undergraduate students, 7 teaching interns, and 8 novice teachers. All had backgrounds in Chinese language education, with formal qualifications in creative writing instruction and national-level teaching certifications (secondary or above).

Recruitment was conducted via the university's academic affairs office and a local education bureau training program for new teachers. The study received ethical approval, and informed consent was obtained from all participants. As incentives, participants received a 20-hour research-based learning certificate and a personalized teaching skill profile. Six participants (2 male, 4 female) were randomly selected for in-depth interviews to ensure diversity and representativeness in qualitative data.

Fuzzy Guidance System Design

To operationalize the pedagogical concept of fuzzy guidance into an interactive AI system, we developed a dual-platform environment that simulates the full process from teacher

questioning to learner conceptual construction. The system consists of two integrated components: a creative writing design platform and a fuzzy concept cloud platform. Together, they aim to recreate the heuristic instructional style of expert teachers by embracing ambiguity, enabling semantic plasticity, and offering non-deterministic feedback. The overall design encourages pre-service teachers to shift their perception of teaching from knowledge transmission to cognitive facilitation.

The core interaction process follows a structured path: question, exploration, and focus. Users begin by setting instructional goals, writing genre, and language style. Based on these parameters, the system generates fuzzy prompts—often in the form of analogies or reflective questions—that simulate the heuristic questioning style used by human instructors. Upon responding, the system extracts key terms and forwards them as “seed concepts” to the fuzzy concept cloud, where users engage in freeform semantic exploration. They can extend, connect, and refine conceptual nodes, eventually narrowing their focus to build structured instructional content.

The fuzzy concept cloud is built using a graph attention network (GAT) architecture over semantic vectors generated by the BGE-M3 model. This allows dynamic calculation of concept relevance based on attention-weighted similarity. Unlike traditional recommender systems, our platform supports open-ended semantic construction. Users can add arbitrary concepts, manually connect unrelated terms to provoke cross-domain associations, and adjust edge weights to express personal judgments. These capabilities transform the cloud from a static suggestion engine into a generative cognitive tool, supporting behaviors akin to a teacher’s selective attention and associative reasoning. A tunable “fuzziness level” parameter controls concept expansion range and path complexity, ensuring that exploration remains cognitively challenging without becoming overwhelming.

To ensure the system adapts to different cognitive demands across writing tasks, we implemented genre-specific semantic expansion logics. In narrative mode, the graph em-

phasizes emotional cues and temporal structure; in expository mode, it strengthens hierarchical and causal reasoning; in argumentative writing, it highlights contrastive logic and evidentiary chains; and in fiction writing, it promotes nonlinear narrative construction and imaginative links. These differentiated expansion strategies are informed by genre cognition theories and help align fuzzy guidance with each genre's unique conceptual scaffolding needs.

The interface was designed in accordance with the principle of progressive clarification. The initial graph state is deliberately ambiguous, and no search function is provided. This discourages goal-driven retrieval and encourages exploratory interaction, where users gradually build their own conceptual frameworks. The interaction design mimics the pedagogical pattern of “letting students discover meaning” rather than receiving direct answers. All user behaviors—such as click paths, node selections, and link formations—are fully logged to provide rich behavioral data for analyzing identity transformation. System latency is optimized to maintain alignment with human cognitive pacing (< 300ms), and full cross-device synchronization ensures usability across classroom and practicum contexts.

In sum, the system embodies fuzzy pedagogical principles through a design that is structurally configurable, semantically open-ended, and behaviorally traceable. It provides pre-service teachers with an authentic simulation of teacher cognition while offering a new design pathway for identity-centered human–AI collaboration in education.

Study Procedure

The study followed a four-stage progressive design aimed at evaluating the impact of fuzzy-guided AI interaction on the transformation of teaching identity in pre-service teachers. The longitudinal flow was structured to capture initial cognitive baselines, mid-intervention responses, internalization patterns, and final outcome verification.

In the first stage (Week 1), we established participants'

baseline identity profiles. All 18 pre-service language teachers completed three instruments: a teaching identity scale (assessing traditional authority beliefs, heuristic orientation, and professional anxiety), an AI-based teaching interaction scale (measuring expectations and attitudes), and a creative writing instruction confidence scale. Afterward, participants were introduced to the dual-platform system via a standardized walkthrough session to ensure a shared understanding of system logic and affordances.

The second stage (Weeks 2–3) comprised the core intervention. Participants engaged intensively with the system across four creative writing genres. For each task, they specified instructional goals, genre type, and stylistic preferences, prompting the system to generate genre-relevant heuristic questions. After responding, the system extracted seed concepts via semantic analysis and shifted the user into the fuzzy concept cloud. There, users explored connections between concepts through clicking, linking, and clustering—mirroring the cognitive progression from questioning to conceptual expansion and then focused scaffolding. Each genre was completed twice (8 tasks total). After each, participants filled out a reflection scale measuring perceived fuzziness, cognitive challenge, and degree of inspiration. The system simultaneously recorded behavioral metrics such as click count, path length, and concept dwell time.

In the third stage (Week 4), participants used the system independently without researcher facilitation. They completed at least six additional self-directed teaching design tasks under prompt-free conditions. The same behavioral logging and reflection measures were collected. This stage was designed to assess the degree of internalization of fuzzy-guided behaviors by comparing interaction depth, conceptual diversity, and reflection richness between facilitated and autonomous use.

The final stage (Week 5) evaluated outcome effects. All participants repeated the three pre-test scales for pre-post comparison. In addition, six participants (2 male, 4 female)

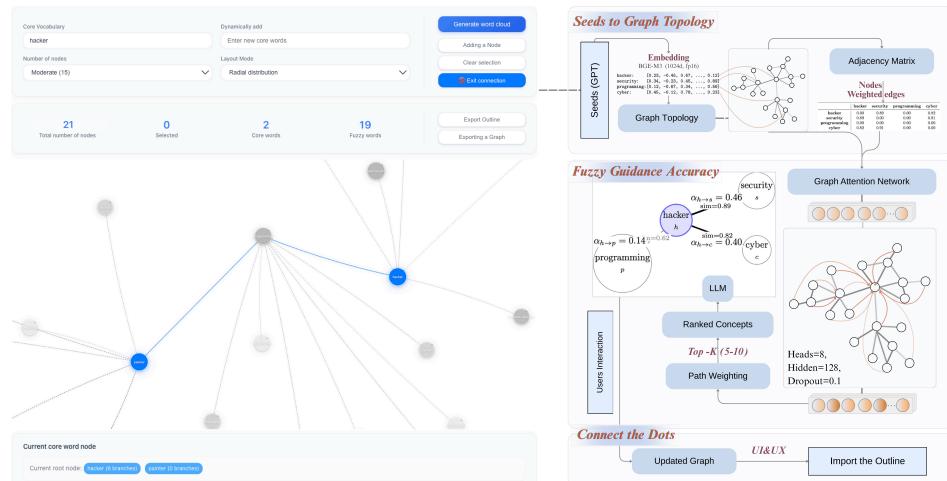


Figure 2: Technical architecture of the ambiguity-driven guidance system.

were randomly selected for 60-minute critical incident recall interviews, focused on moments they felt most cognitively transformed by the system. Interviews were transcribed and independently coded by two researchers to extract identity-related thematic shifts. Quantitative results were analyzed via paired *t*-tests with reported effect sizes and confidence intervals. Log data and qualitative codes were integrated through meta-inference: converging evidence was used to strengthen conclusions, while discrepancies were examined in light of user strategies, task difficulty, and contextual variables.

To ensure transparency and reproducibility, the study was pre-registered. All measurement instruments, interview protocols, system parameters, and logging specifications will be anonymized and shared publicly upon completion.

Measurement Instruments and Data Integration

The transformation of teaching identity in pre-service educators is a dynamic and multi-dimensional process. It involves shifts from valuing authoritative knowledge to embracing heuristic guidance, from delivering direct answers to favoring inquiry-based teaching, and from anxiety about AI involvement to emotional acceptance of human–AI collaboration. To address this complexity, we operationalized identity transformation across three latent dimensions: cognitive reconstruction, behavioral preference, and emotional adaptation. In parallel, the experience of fuzzy guidance was assessed through its effects on cognitive activation, exploratory enjoyment, and pedagogical inspiration.

Pre- and post-test instruments consisted of semantically equivalent 5-point Likert scales measuring each identity dimension. Items were minimally adjusted for temporal framing to ensure consistency across timepoints. During the intervention phase, participants completed immediate reflection questionnaires after each design task. These captured real-time impressions of ambiguity intensity, cognitive challenge, and perceived inspiration, thereby reducing recall bias and enabling fine-grained tracking of experiential dynamics.

Qualitative data were collected through critical incident prompting, where participants were asked open-ended questions such as “At what moment did your view of good teaching shift?” These interviews aimed to surface deep meaning reconstructions not easily captured by structured surveys.

To ensure instrument validity, the scales underwent expert review, small-sample piloting, and item-level discrimination analysis. Poorly performing items were removed, and ambiguous language was revised. Interview transcripts were coded independently by two researchers, using a collaboratively developed coding manual that defined inclusion rules and edge cases. System logs—covering keyword matches, path complexity, exploration breadth, and dwell time—were cleaned for outliers and standardized prior to analysis.

For triangulated validation, we employed convergent mixed-method analysis: quantitative changes were aligned with behavioral patterns and interpretive themes. When all three data sources converged, findings were considered strongly supported. In cases of discrepancy, we performed contextual analysis based on usage strategies, task difficulty,

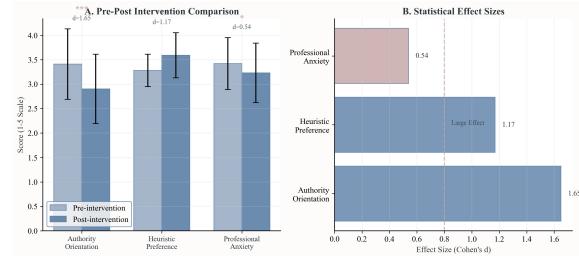


Figure 3: Pre-post comparison of teaching identity dimensions.

and individual differences—allowing for richer explanation of identity transformation mechanisms.

Results

Quantitative Findings: From Substitution Anxiety to Collaborative Confidence

Our intervention targeted three core dimensions of professional identity: traditional authority beliefs, heuristic teaching preference, and AI-related anxiety. Paired-sample *t*-tests revealed significant changes across all indicators, outlining a clear trajectory of transformation (Figure 3). Authority beliefs declined substantially, from 3.42 ± 0.72 to 2.90 ± 0.71 ($t(17) = 7.01$, $p < .001$, Cohen's $d = 1.65$), indicating a fundamental challenge to knowledge-transmission models. At the same time, preference for heuristic teaching increased significantly, from 3.28 ± 0.33 to 3.59 ± 0.46 ($t(17) = -4.96$, $p < .001$, $d = 1.17$), signaling a genuine acceptance of inquiry-based pedagogy. Accompanying this identity shift, professional anxiety related to AI showed moderate relief, decreasing from 3.42 ± 0.53 to 3.23 ± 0.61 ($t(17) = 2.31$, $p < .05$, $d = 0.54$).

These attitudinal shifts were strongly reinforced by behavioral evidence. On average, participants engaged in 39.9 exploratory clicks, built 122.8 conceptual path steps, and spent 9.8 minutes in focused exploration per task—patterns indicative of deep cognitive engagement. Most importantly, the change in heuristic preference was strongly correlated with exploration intensity ($r = 0.65$, $p < .01$), demonstrating that ambiguity-driven interaction not only reshaped teaching beliefs but also cultivated sustained habits of exploration and reflection.

Cluster analysis further revealed three distinct modes of identity transformation (Figure 4). Deep Transformation ($n = 5$, 28%) represented open-minded pre-service teachers who showed substantive improvements across all dimensions, reflecting a comprehensive reconstruction of professional identity. Gradual Adaptation ($n = 9$, 50%) formed the largest subgroup, characterized by significant gains in heuristic preference accompanied by moderate declines in authority beliefs, indicating steady adaptive change. Most intriguingly, Authority Persistence ($n = 4$, 22%) showed minimal shifts in survey measures but exhibited the most active exploration behaviors, suggesting that deeper cognitive restructuring may require longer time horizons to surface in explicit attitudes.

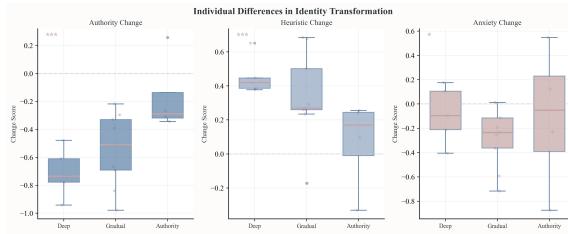


Figure 4: Three distinct patterns of identity transformation.

Qualitative Themes: Rediscovering the Unique Value of Teaching

To unpack the mechanisms behind these quantitative changes, we conducted in-depth interviews with six participants.

The most salient theme was a repositioning of role—from knowledge transmitter to facilitator of thought. Participants consistently described a reconfiguration of pedagogical identity. For instance, P01 (new teacher, authority -0.3 , heuristic $+0.7$) explained:

"I found that ambiguous prompts often stimulated deeper thinking than explicit instructions. Each click felt like opening a new door—the appeal of the unknown kept me exploring."

This experiential discovery resonated across different participant profiles. P13 (pre-service teacher, moderate change) emphasized the balancing act:

"I am learning how to maintain professional authority while still giving students more space to think. It's a skill that requires continuous practice."

A second theme highlighted ambiguity as cognitive catalyst. While many initially expressed discomfort with uncertainty, they later recognized its value for intellectual engagement. P18 (new teacher, anxiety -0.7) reflected:

"Although I sometimes felt lost, the confusion sparked new ideas. I still prefer clear guidance, but I've begun to see that uncertainty has its own value."

This process helps explain the behavioral data—particularly the persistence and complexity of exploratory paths—by showing how moderate ambiguity sustains cognitive tension and fosters reflective thinking.

Finally, participants described an emotional shift from caution to acceptance, which often preceded cognitive transformation. P09 (new teacher, anxiety -0.9 , heuristic stable) noted:

"The system made me realize that the teacher's role is richer than I imagined. The uncertainty was uncomfortable, but it pushed me to engage more. My beliefs didn't change much, but I now see positive possibilities."

Evidence Convergence: Triangulating Mechanisms

When survey data, behavioral logs, and interview accounts converge, the credibility of our findings is substantially reinforced. Consistency cases highlight shared mechanisms

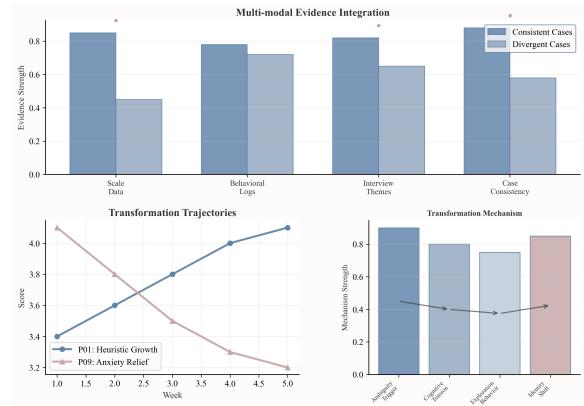


Figure 5: Triangulation analysis.

across modalities. For example, P01 showed a clear trajectory: an 8% decline in authority beliefs, a 20% increase in heuristic preference, and 57 exploratory clicks with an average intensity of 5.8 clicks per minute. In interviews, she explicitly described the “magnetic pull” of exploring semantic expansions, reinforcing the behavioral and attitudinal evidence.

Divergence cases, in contrast, illuminate transitional states in identity reconstruction. P09 exhibited a slight decrease in heuristic preference (-0.3) alongside a significant reduction in anxiety (-0.9). Although his survey responses suggested minimal pedagogical change, interviews revealed a deeper recognition of the richness of teaching roles. As visualized in Figure 5, such seemingly contradictory patterns suggest that identity reconstruction follows nonlinear trajectories: emotional adaptation may precede cognitive transformation, and deeper shifts in role understanding may require longer time horizons to surface in explicit measures.

Taken together, these findings suggest a layered mechanism of transformation. Ambiguity first creates cognitive tension, exploration behaviors serve as a mediating process, and sustained engagement eventually culminates in systematic reconfiguration of professional identity.

Discussion

From Content Delivery to Cognitive Mediation

Our results demonstrate a significant reframing of teacher identity: participants moved away from affirming “knowledge authority” and toward a preference for heuristic, inquiry-based teaching. This shift reflects a broader adaptation to the AI era, in which information delivery is increasingly automated while human educators’ comparative advantage lies in guiding thinking rather than providing answers.

Importantly, this is not merely an attitudinal change but a structural redefinition of professional value. Each interaction with the system acted as a reflective mirror, reframing the teacher’s role from that of a content provider to a designer of cognitive pathways. This suggests that when technology is deliberately structured to amplify ambiguity, it can catalyze

shifts in professional identity and pedagogical intentionality.

Operationalizing Educational Ambiguity in HCI

Behavioral logs and interviews together revealed a striking transition: participants moved from “seeking correct answers” to “embracing exploration.” What began as confusion was increasingly reframed as productive ambiguity, where uncertainty became a catalyst for reflection and deeper thought.

This finding resonates with educational psychology frameworks such as the Zone of Proximal Development (Vygotsky, 1978) and desirable difficulties (Bjork & Bjork, 2011). Our results suggest that when AI systems withhold definitive answers and instead construct structured spaces of ambiguity, users actively build their own cognitive scaffolds, engaging in more sustained and effortful processing.

We formalize this into a design principle of *ambiguity-driven precision*: by intentionally introducing incompleteness and nonlinearity into interaction flows, systems can stimulate user agency and associative reasoning. Here, ambiguity is not a flaw but a designable cognitive lever.

This principle challenges the dominant paradigm of AI in education, which emphasizes output efficiency and correctness. For the HCI community, it offers a new paradigm: turning pedagogical ambiguity into interactional value, expanding how we conceptualize human–AI collaboration in learning contexts.

Designing for Conceptual Exploration over Answer Retrieval

System logs and interview data revealed that participants gradually moved away from a reliance on “finding the right answer” and toward actively shaping conceptual nodes and connections within the interface. This behavioral shift not only reflects improved control over the interface but also signals a deeper change in cognitive orientation—from passive recipients of content to active constructors of meaning. Unlike traditional AI writing tools that emphasize efficiency and correctness, our ambiguity-driven concept cloud deliberately sustained uncertainty and openness, stimulating participants’ motivation to explore and refine their own understanding of writing tasks.

In this setting, AI was reframed from a solution provider into a cognitive scaffold. Participants no longer optimized for task completion speed; instead, they derived value from the iterative process of exploration and adjustment. The system’s ambiguous feedback, evolving concept graphs, and carefully tuned pacing created a space where “unfinished thinking” could persist and be refined. This enabled users to practice the very skills of cognitive guidance that are central to effective teaching. The findings suggest that the critical design challenge in educational AI is not determining what content to provide, but rather what structures and rhythms to design so that users are motivated and able to think like teachers.

Scaling Cognitive Scaffolding for Educational Equity

Pre-service teachers occupy an early stage of professional identity formation, where cognitive structures are still malleable and pedagogical commitments are highly sensitive to context. Their strong receptivity to ambiguity-driven guidance indicates not only alignment with their developmental needs but also the potential for scaling impact beyond the individual level. As future practitioners, their cognitive paradigms will be enacted in classrooms, shaping the learning trajectories of their students and, by extension, the broader educational ecosystem.

Equally important, the system itself offers practical affordances for equity. Its open-ended structure and low technical barriers do not require finely annotated datasets or complex configurations, making it adaptable across regions and institutions, including resource-constrained settings. In this sense, ambiguity-driven guidance is both a pedagogical philosophy and a scalable design strategy: it provides teachers who lack extensive mentoring with structured opportunities for cognitive construction, thereby enhancing systemic fairness. By grounding equity not only in access but in cognitive empowerment, our approach highlights a novel pathway for HCI to contribute to the redistribution of educational opportunity.

Limitations and Future Directions

While this study provides initial evidence for the theoretical and practical value of ambiguity-driven guidance, several limitations must be acknowledged. First, the participant pool was limited to 18 pre-service Chinese language teachers from a single region. Broader studies involving teachers from diverse cultural and disciplinary backgrounds are necessary to test the cross-context adaptability of the mechanism. Second, our intervention focused on four genres of creative writing. Whether ambiguity-driven scaffolding extends to more structurally constrained domains such as scientific experiment design, historical reasoning, or mathematical modeling remains an open question.

Third, the five-week study period captured short-term transformations but was insufficient to observe long-term identity trajectories. Teacher identity is inherently a dynamic process shaped by socialization and practice; future work should adopt longitudinal field designs that integrate classroom observation and teaching feedback to assess the stability and depth of cognitive change.

Finally, the current system focused on the dyad of teacher–AI interaction, without incorporating the full triadic ecology of student–teacher–AI collaboration. In real classrooms, AI should not only augment teachers’ cognition but also serve as a mediator between teacher guidance and student creativity. Future research should explore how AI can flexibly shift roles across multiple stakeholders, enabling real-time negotiation and co-construction in classroom contexts. Such work would not only extend system functionality but also provide a critical test of whether ambiguity-driven guidance can sustain agency and equity in authentic educational ecosystems.

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References

- Amershi, S., et al. (2019). Guidelines for Human–AI Interaction. CHI ’19.
- Azevedo, R., & Aleven, V. (Eds.). (2013). International handbook of metacognition and learning technologies. Springer.
- Beauchamp, C., & Thomas, L. (2009). Understanding teacher identity: An overview of issues in the literature and implications for teacher education. *Cambridge Journal of Education*, 39(2), 175–189.
- Beijaard, D., Meijer, P. C., & Verloop, N. (2004). Reconsidering research on teachers’ professional identity. *Teaching and Teacher Education*, 20(2), 107–128.
- Bjork, R. A., & Bjork, E. L. (2011). Making things hard on yourself, but in a good way: Creating desirable difficulties to enhance learning. *Psychology and the Real World*.
- Bruner, J. S. (1966). Toward a Theory of Instruction. Harvard University Press.
- Clough, P. (2010). Narratives and fictions in educational research. McGraw-Hill Education.
- Darling-Hammond, L. (2010). Teacher education and the American future. *Journal of Teacher Education*, 61(1-2), 35–47.
- Emig, J. (1977). Writing as a mode of learning. *College Composition and Communication*, 28(2), 122–128.
- Giddens, A. (1991). Modernity and self-identity: Self and society in the late modern age. Stanford University Press.
- Holstein, K., McLaren, B. M., & Aleven, V. (2019). The Co-Author Perspective: Investigating the Effectiveness of Human-AI Collaboration in Writing. Proceedings of the 2019 CHI conference on human factors in computing systems, 1–16.
- Kasneci, E., et al. (2023). ChatGPT for good? On opportunities and challenges of large language models for education. *Learning and Individual Differences*.
- Kaufman, J. C., & Beghetto, R. A. (2009). Beyond big and little: The four c model of creativity. *Review of General Psychology*.
- Lajoie, S. P. (2005). Extending the scaffolding metaphor. *Instructional Science*, 33(5-6), 541–557.
- Lee, M., Liang, P., & Yang, Q. (2022). Coauthor: Designing a human-AI collaborative writing dataset for exploring language model capabilities. Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems, 1–19.
- Lee, S. Y., Fan, M., Wang, D., & Kim, J. (2024). A design space for intelligent and interactive writing assistants. CHI ’24.
- Lortie, D. C. (1975). Schoolteacher: A sociological study. University of Chicago Press.
- Sawyer, R. K. (2011). The Cambridge handbook of the learning sciences (2nd ed.). Cambridge University Press.
- Vygotsky, L. S. (1978). Mind in society: The development of higher psychological processes. Harvard University Press.