Mechanisms of Collective Knowledge Advancement in Knowledge-Building Communities: A Perspective from Epistemic Emotion

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Abstract: *This study investigates how epistemic emotions and discourse moves interact to support collective knowledge advancement in a university-level Knowledge Building environment. Thirty-five undergraduate students participated in a ten-week interdisciplinary course using Knowledge Forum®, where they collaboratively engaged in progressive inquiry and tagged their notes with self-reported epistemic emotions. A mixed-methods approach was employed, combining learning analytics and content analysis to compare high and low contributors, alongside thematic analysis of high-engagement discourse episodes. Quantitative results showed that high contributors expressed significantly more epistemic emotions of challenge, neutrality, and enjoyment, and employed more advanced discourse moves, including sustained inquiry and explanation improvement. Qualitative analysis revealed three affective–discursive mechanisms: (1) emotion-driven inquiry that stimulated conceptual expansion, (2) emotionally positioned theorizing that supported conceptual deepening, and (3) emotion-regulated synthesis that enabled collaborative integration of ideas. These findings suggest that epistemic emotions are not peripheral to learning but act as cognitive resources that shape the development of progressive discourse.*

Keywords: knowledge building, collective knowledge advancement, discourse move, epistemic emotion

1. Introduction

The transformation of education to support authentic knowledge creation has become a central concern in the learning sciences (Hoidn & Kärkkäinen, 2014). Among the frameworks developed in response to this challenge, Knowledge Building offers a distinctive approach in which classrooms are conceptualized as knowledge-creating communities. In these communities, learners collaboratively engage in the *improvement of ideas*, with the central goal of advancing community knowledge (Scardamalia & Bereiter, 2014). Rather than prioritizing individual acquisition or comprehension, Knowledge Building emphasizes epistemic agency, collective responsibility, and the co-construction of conceptual artifacts that are improvable and valuable to the wider community. To support such inquiry, Knowledge Forum® provides a digital environment where students can pose problems, articulate emerging theories, and refine ideas through sustained discourse. Scaffolds such as “my theory,” “a better theory,” and “putting our ideas together” are embedded within the platform to promote metacognitive reflection and progressive discourse. Prior research has examined how students engage in discourse practices—such as explanation, elaboration, and theory building—that contribute to collective knowledge advancement (Chen & Hong, 2016). Building on this foundation, our earlier work designed a Knowledge Building environment in which undergraduate students engaged in self-directed learning trajectories and reflected on their participation in community knowledge processes. Through iterative design-based research, we found that students developed deeper epistemic awareness, adopted increasingly sophisticated discourse strategies, and made more substantial contributions to collective knowledge advancement over time (Feng, et al., 2023).

While discourse-centered analyses have yielded critical insights into the cognitive and collaborative dimensions of Knowledge Building, relatively limited attention has been devoted to the affective experiences that accompany and potentially shape students' engagement in knowledge-building processes. *Epistemic emotions* — such as curiosity, confusion, interest, and frustration— are known to arise in contexts involving uncertainty, complexity, or conceptual conflict. These emotions are not merely by-products of learning but are increasingly recognized as playing a constitutive role in students' engagement, persistence, and responsiveness during inquiry. Emerging studies have begun to explore how epistemic emotions manifest in Knowledge Building environments. For example, Zhu et al. (2021) found that refining Knowledge Building practices based on student feedback contributed to more positive emotional engagement. Teo et al. (2022) employed multimodal data to show that epistemic emotions vary dynamically during collaborative idea development. These findings suggest that emotional experiences are deeply embedded in knowledge-building participation and may influence how learners interact with ideas and with one another.

Despite these developments, few studies have systematically examined how epistemic emotions and discourse moves are enacted together in the process of collective knowledge advancement. Moreover, it remains unclear whether and how emotional and discursive engagement differ among students who contribute substantively to the improvement of community knowledge. Addressing this gap, the present study investigates how undergraduate students' epistemic emotions and discourse practices relate to their contributions to collective knowledge advancement in a university-level Knowledge Building course. The course emphasized self-directed inquiry and sustained engagement with community ideas. Students tagged their written contributions with self-reported epistemic emotions, enabling a detailed analysis of the co-occurrence between emotion and discourse. We focus on how these dimensions vary among students with differing levels of contribution to community knowledge advancement, and how they are enacted in the context of progressive inquiry. This study is guided by the following research questions:

1. To what extent do high and low contributors differ in their use of epistemic emotions and discourse moves associated with collective knowledge advancement?
2. How did undergraduates engage in epistemic emotions and discourse moves towards collective knowledge advancement?

By examining the emotional and discursive dynamics that underpin collective knowledge advancement in Knowledge Building, this study seeks to advance a more integrated understanding of how affective and cognitive practices jointly support knowledge-creating participation in collaborative learning environments.

2. Methods

2.1. Participants

Thirty-five undergraduate students from a science and engineering university in Shenzhen, China, participated in this study. All participants were enrolled in a liberal arts elective course titled *Education and Modern Technology*, which was offered to students from diverse science and engineering majors. The course aimed to foster interdisciplinary inquiry into the relationship between education, society, and technological development. Participation in the study was voluntary, and all students provided informed consent.

2.2. Knowledge Building context and pedagogical design

This ten-week course, *Education and Modern Technology*, was designed as an interdisciplinary elective for undergraduate science and engineering students. It was grounded in the principles of Knowledge Building, which conceptualizes education as a process of collectively advancing ideas within a knowledge-creating community (Scardamalia & Bereiter, 2014). The pedagogical design emphasized sustained inquiry, epistemic agency, and progressive discourse. All collaboration occurred within Knowledge Forum®, a computer-supported collaborative learning platform enabling students to post notes, build on each other's ideas, and visualize discourse. To support metacognitive and affective engagement, students were encouraged—but not required—to use two types of scaffolds when composing notes: (1) *Epistemic discourse scaffolds*, including prompts such as "My idea", "A better idea", and "Putting our ideas together", aimed to guide sustained inquiry. (2) *Epistemic emotion scaffolds*, including "confused", "challenged", "surprised", "curious", "neutral", "frustrated", and "happy", supported students' reflection on affective experiences during inquiry. The learning process unfolded through three emergent phases of collective inquiry, each representing a shift in epistemic goals and discourse engagement.

2.2.1. Phase 1: Ideation (Weeks 1–3)

Students initiated inquiry by engaging with foundational prompts such as Our Vision for Education and The History of Education and Technology. Through collaborative exploration, they identified key issues related to educational purpose, modern vs. traditional technologies, learning theories, social relations, and team collaboration. Epistemic discourse scaffolds were frequently used to articulate, refine, and connect ideas, while emotion tags enabled reflection on cognitive challenges and curiosity.

As illustrated in Figure 1, one group centered their inquiry on the core problem: How can educational equity be effectively achieved amid educational transformation? Their dialogue expanded into subtopics such as education and social change, education transformation and policy, social development, and talent needs. Through iterative discourse, the group collaboratively co-created a problem-solving poster, synthesizing their key insights and proposing actionable directions for change.

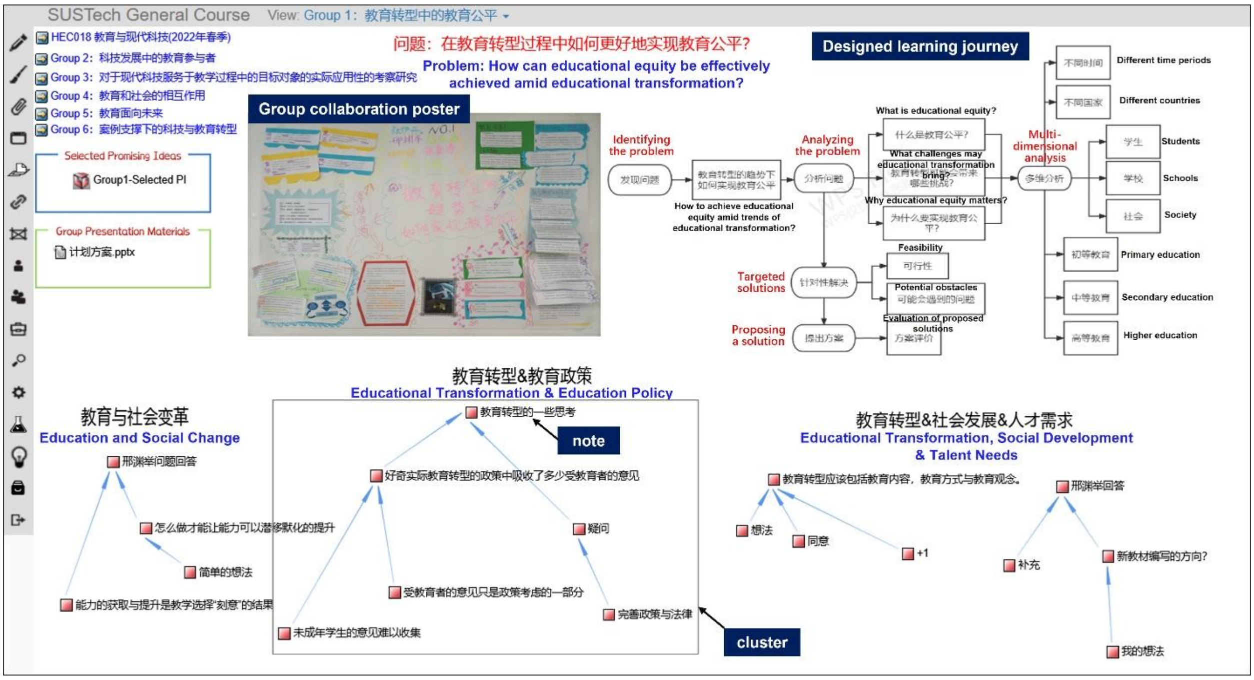

Fig. 1 A Knowledge Forum view

2.2.2. Phase 2: Learning journey design (Weeks 4–6)

Building on their initial exploration, students engaged in designing visual models of their inquiry trajectories — referred to as learning journeys — to reflect how their understanding evolved over time. These models were shared in Knowledge Forum for peer feedback, allowing the learning community to collectively reflect on the processes of theory refinement and idea improvement.

As shown in Figure 2, different groups emphasized distinct aspects of inquiry: one model highlighted the importance of collaboration and reflection, while another underscored iteration and feedback loops. Despite stylistic variation, all models demonstrated a shared epistemic commitment to progressive idea improvement, aligning with core Knowledge Building principles.

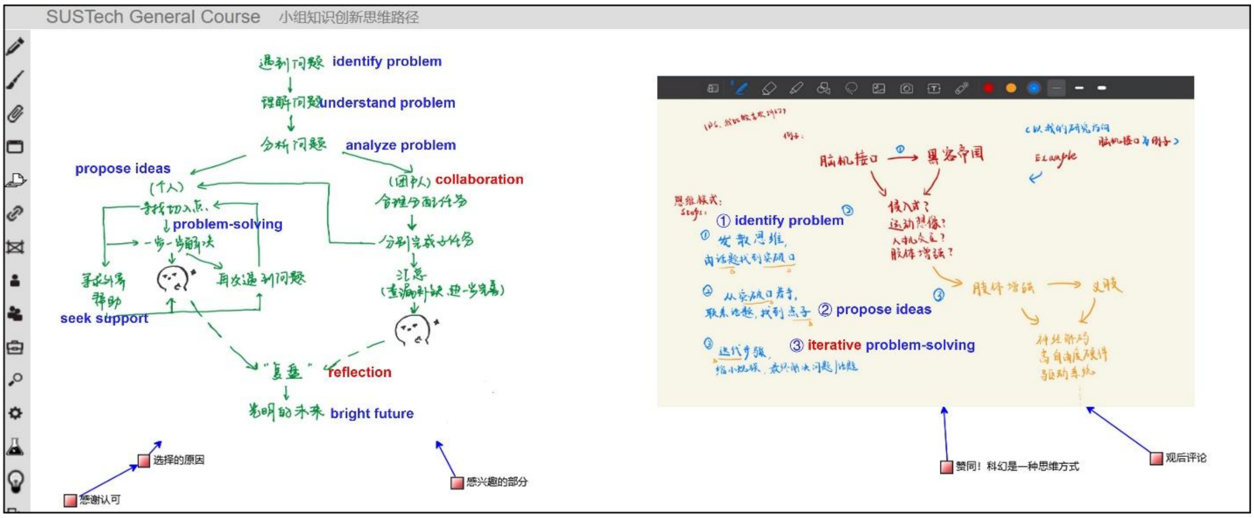

Fig.2 Student designed learning journey for Knowledge Building

2.2.3. Phase 3: Progressive idea improvement with the designed learning journey (Weeks 7–10)

In the final phase, students extended their inquiry into broader conceptual domains, drawing from historical, philosophical, and systemic perspectives on education and technology. Each of the six groups selected a thematic focus—such as educational equity, technological transformation, or education and social development—and pursued sustained investigation through collective discourse.

Revisiting Figure 1, the group exploring educational equity deepened their inquiry into the subdomains of policy innovation, social inclusion, and talent development. Their earlier learning journey served as a conceptual scaffold, helping them align discourse with thematic goals and maintain coherence across inquiry episodes. Each group synthesized their findings into a collaborative poster, representing both a knowledge artifact and a shared contribution to community understanding.

2.3. Data Sources and data analysis

The primary dataset consisted of 328 notes authored by 35 students over ten weeks of collaborative discourse in Knowledge Forum®. The analysis proceeded in three stages, combining quantitative comparisons and qualitative interpretation to examine students' emotional and discourse engagement in relation to their contribution to collective knowledge advancement.

2.3.1. Identifying contribution levels

The learning analytics tool KBDeX (Oshima et al., 2012) was utilized to distinguish undergraduates with high and low contributions to collective knowledge advancement. According to knowledge-building research on KBDeX, a higher Total Degree Centrality denotes more collective knowledge advancement (Oshima et al., 2021). Here, *Note Contribution* is defined as the contribution of a note to collective knowledge advancement and calculated as the difference in Total Degree Centrality between the current and the previous Knowledge Forum discourse (note) network. Then each note's author was identified to calculate each student's contribution to the collective knowledge advancement (Feng et al., 2020). Finally, 17 students were identified as high contributors, while 18 were identified as low contributors.

2.3.2. Emotion and discourse coding with statistical analysis

The study compared undergraduates' engagements of epistemic emotions and discourse moves between high and low contributors using content analysis. Firstly, the numbers and percentages of students' epistemic emotions of *confusion*, *challenged*, *surprise*, *curiosity*, *neutral*, *frustration*, and *enjoyment* (Han et al., 2021; Teo et al., 2022; Zhu et al., 2022) from each Knowledge Forum note were calculated (students labeled their epistemic emotions in each Knowledge Forum note when creating it). Then students' Knowledge Forum notes were coded with a coding framework composed of several categories, including *Questioning*, *Theorizing*, and *Community*. These categories draw upon theoretical frameworks for progressive inquiry (Hakkarainen, 2003) and knowledge creation (Chuy et al., 2011). Coding for each note was done independently by two raters, who then came together for social moderation to reach an agreement (Cohen's kappa= .79). Disagreements were settled after discussion. Finally, the epistemic emotions and discourse moves adopted by high and low contributors were compared using one-way MANOVA.

2.3.3. Thematic analysis of high-engagement episodes

To complement the quantitative findings, a qualitative thematic analysis was conducted on selected notes that exemplified students' integration of epistemic emotions and discourse practices in the process of idea improvement. This analysis sought to uncover how emotional and cognitive engagement co-occurred in episodes of productive discourse, thereby enriching our understanding of the mechanisms supporting community knowledge advancement.

3. Results

3.1. RQ1: To what extent do high and low contributors differ in their use of epistemic emotions and discourse moves associated with collective knowledge advancement?

3.1.1. Differences in epistemic emotions

Table 1 presents the frequencies and proportions of epistemic emotions expressed by high and low contributors. High contributors reported higher levels of *challenged* (17.48% vs. 15.57%), *neutral* (35.44% vs. 30.33%), and *enjoyment* (25.73% vs. 24.59%) emotions, as well as slightly more instances of *frustration* (2.43% vs. 0.82%). In contrast, low contributors expressed more *confusion* (13.11% vs. 7.28%) and *surprised* (4.10% vs. 1.46%) emotions.

A one-way MANOVA revealed a significant overall difference in the use of epistemic emotions between the two groups, $F(7, 27) = 3.90$, $p = .005$, Wilks' $\Lambda = .50$, partial $eta^2 = .50$. Follow-up univariate ANOVAs indicated that high contributors expressed significantly more *challenged* ($F(1, 33) = 4.60$, $p = .039$, partial $eta^2 = .12$), *neutral* ($F(1, 33) = 15.98$, $p < .001$, partial $eta^2 = .33$), and *enjoyment* ($F(1, 33) = 4.54$, $p = .041$, partial $eta^2 = .12$) emotions. These findings suggest that students who expressed greater levels of emotional engagement – particularly emotions such as *challenged*, *neutral*, and *enjoyment* – were more likely to contribute meaningfully to the community's collective knowledge advancement.

Table 1. *Frequencies and percentages of epistemic emotions conducted by high and low contributors*

	High contributors		Low contributors	
	f	% (f/206)	f	% (f/122)
Confusion	15	7.28	16	13.11
Challenged	36	17.48	19	15.57
Surprised	3	1.46	5	4.10
Curiosity	21	10.19	14	11.48
Neutral	73	35.44	37	30.33
Frustration	5	2.43	1	0.82
Enjoyment	53	25.73	30	24.59

3.1.2. Differences in discourse moves

As shown in Table 2, the high contributors used more higher-level discourse moves than the lower contributors. For example, compared with low contributors, they engaged in more *sustained inquiry* (12.14% vs. 6.56%), *improving an explanation* (17.48% vs. 12.30%), and *lending support* (4.85% vs. 4.10%). One-way MANOVA results reveal a significant difference in students' usage of discourse moves between the high and low contributors, $F(8, 26) = 3.53$, $p = .007$, Wilks' $\Lambda = .48$, partial $eta^2 = .52$. In follow-up univariate ANOVAs, higher contributors show significantly higher values of *Questioning-sustained inquiry* ($F(1, 33) = 7.12$, $p = .012$, partial $eta^2 = .18$), *Theorizing-supporting an explanation* ($F(1, 33) = 8.55$, $p = .006$, partial $eta^2 = .21$), and *Theorizing-improving an explanation* ($F(1, 33) = 9.47$, $p = .004$, partial $eta^2 = .22$). These results indicate that student who contributed more substantively to collective knowledge advancement tended to engage in deeper *Questioning* and more sophisticated *Theorizing*, supporting the emergence of progressive discourse.

Table 2. *Frequencies and percentages of discourse moves used by high and low contributors*

	High contributors	Low contributors

	f	% (f/206)	f	% (f/122)
Questioning				
Explanation seeking (ES)	12	5.83	8	6.56
Sustained inquiry (SI)	25	12.14	8	6.56
Theorizing				
Proposing an explanation (PE)	69	33.50	54	44.26
Supporting an explanation (SE)	40	19.42	19	15.57
Improving an explanation (IE)	36	17.48	15	12.30
Community				
Synthesis (SS)	2	0.97	1	0.82
Shared regulation (SR)	12	5.83	13	9.84
Lending support (LS)	10	4.85	5	4.10

3.2. RQ2: How did undergraduates engage in epistemic emotions and discourse moves towards collective knowledge advancement?

To investigate how undergraduates engaged in epistemic emotions and discourse moves to support collective knowledge advancement, we conducted a thematic analysis of discourse episodes contributed by high-contributing students. The analysis revealed three interrelated mechanisms through which epistemic emotions and discourse practices were dynamically coupled to foster progressive discourse. Each theme corresponds to a distinct phase of knowledge-building: conceptual expansion, conceptual deepening, and collaborative integration.

3.2.1. Emotion-driven inquiry as a trigger for conceptual expansion

Epistemic emotions such as *curiosity*, *challenged*, and *frustration* served as affective triggers that prompted students to generate open-ended questions and initiate sustained inquiry. These emotionally charged questions helped expand the problem space and led the group into new conceptual territories.

For instance, when discussing *Educational Transformation*, student s31 expressed curiosity about the extent to which learners' ideas are incorporated into policymaking:

[I feel curious] How much weight should the ideas of the educated take in the policy formulation of educational transformation? … I am curious about how many ideas of educated people were incorporated when formulating policies for educational transformation.

This inquiry prompted peers to consider the tension between idealistic student voice and practical policy constraints. Similarly, in a discussion on The Impact of Technology on Education, student s29 expressed challenge in navigating the information landscape:

[I feel challenged] The threshold for obtaining knowledge is getting lower… How to extract high-quality information from massive amounts of information is a new challenge for technology and individuals.

Following this, student s06 posed a critical question about whether lowered educational thresholds could lead to a decline in teaching quality:

[I feel challenged] Would lowering the educational threshold lead to a decline in the average level of teaching staff?

In another discussion, student s25 expressed frustration about the difficulty of self-understanding and posed a new question about how education can help individuals identify their interests and talents:

[I feel frustrated] I often have a feeling that I don't necessarily know myself… I think education can provide a more effective way for me to discover my own interests and talents?

These emotionally driven questions illustrate how epistemic emotions functioned as catalysts for conceptual expansion, opening up new avenues for inquiry and community engagement.

3.2.2. Emotionally positioned theorizing for conceptual deepening

Students also used epistemic emotions to frame and position their theoretical stances, often in the form of neutral, challenged, or frustration. These emotions accompanied discourse moves such as improving explanations and elaborating ideas, signaling students' efforts to refine, evaluate, or reframe existing contributions.

For example, in the discussion on Educational Transformation, student s01 neutrally elaborated on vocational education and labor market dynamics:

[I feel neutral] Professionals should integrate the social situation with the school's educational achievements… For example, studying for a postgraduate to find a job, but not every position requires the research ability of a postgraduate.

This positioned explanation built on earlier ideas and led peers like s26 to further integrate perspectives on individual development and societal needs. In another discussion on What is Education, student s33 expressed frustration regarding current assessment systems:

[I feel frustrated] The assessment criteria of the education system are sometimes not diverse enough… The most important thing is to find the one that suits you.

This emotionally positioned challenge prompted further elaboration from peers on the need for diverse evaluation methods and personalized learning.

In each case, emotions helped students frame their epistemic stance, providing both a cognitive and social signal that invited deeper engagement and theory refinement. These episodes reflect a process of conceptual deepening, where emotional cues guided the community toward more elaborated and coherent explanations.

3.2.3. Emotion-regulated synthesis for collaborative integration

Students used emotionally regulated discourse—particularly involving neutral or challenged expressions—to synthesize diverse ideas and set new directions for group inquiry. These emotionally modulated contributions enabled students to integrate prior ideas and structure collective understanding, supporting collaborative integration.

For instance, in the Educational Transformation discussion, student s14 challenged the group to adopt a future-oriented perspective:

[I feel challenged] Education transformation should be future-oriented—to the values of the people in the future, the technology of the future, and the society of the future… We should pay more attention to future development and plan for the transformation of education.

This forward-looking synthesis led to a series of elaborations from peers on curriculum reform, educational equity, and social change. Similarly, student s29 neutrally synthesized multiple group perspectives on the relationship between education, society, and individual freedom:

[I feel neutral] Education should focus on the relationship between individuals and society… However, this kind of freedom is still far from being realized… Such education is a waste of human resources and something we must pay attention to.

This synthesis note served as a conceptual anchor, prompting further inquiry into structural constraints and the potential for educational reform.

These examples illustrate how emotion-regulated synthesis enabled students to manage cognitive complexity and coordinate perspectives, facilitating the integration of ideas into a shared knowledge structure.

4. Discussion and Conclusion

This study demonstrates that epistemic emotions play a functional role in collective knowledge advancement within a Knowledge Building environment. High-contributing students expressed more challenge, neutrality, and enjoyment, and engaged in advanced discourse moves such as sustained inquiry and explanation improvement. Qualitative analysis revealed three mechanisms through which emotions and discourse interacted: emotion-driven inquiry opened new conceptual spaces; emotionally positioned theorizing refined ideas; and emotion-regulated synthesis integrated group perspectives. These findings suggest that emotions are not peripheral to collaborative learning but serve as cognitive resources that scaffold different phases of progressive discourse. By illuminating how affective–discursive dynamics support conceptual expansion, deepening, and integration, this study advances a more holistic understanding of knowledge-building participation. Future work should explore how emotional engagement can be further supported through pedagogical or technological scaffolds in diverse learning contexts.

Acknowledgements

This study is supported by the National Social Science Foundation of China (Grant No. BCA200090), and Guangdong Planning Office of Philosophy and Social Science (Grant No. GD23CJY19).

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教师成为学习设计师的实践探索：专家指导与 AI 协同下 K-12 STEM 课程的五轮迭代研究

Becoming a Learning Designer: Expert Guidance and AI Collaboration in a Five-Iteration Case Study of K-12 STEM

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【摘要】 在 K-12 STEM 教育中，教师面临如何在大班教学中实现高质量探究式学习的挑战。本文采用基于设计的研究方法（Design-based research），基于一位中学 STEM 教师在五轮课程迭代过程中的实践，探讨教师在专家指导与生成式 AI 协同支持下的角色转型机制。研究提出"教师—专家—AI—学生学习证据"协同成长模式，揭示专家指导有助于教师的理念转变的重构对学习设计的理解教学，生成式 AI 可在明确任务下提供高效支持，而学生学习证据反馈机制是推动教师持续优化设计的关键中间变量。该框架为教师从程序性教学向以学生为中心的探究式学习设计转型提供了一种结构化路径，对教师专业成长机制的建构具有实践与理论意义。
【关键词】 学习设计；生成式人工智能；学习证据；教师成长；STEM 教育

Abstract: *This study investigates how expert guidance and generative AI collectively support STEM teachers' transition from traditional instruction to inquiry-based learning design. Through five iterative cycles of design-based research with a secondary teacher, we identify three key mechanisms: (1) experts catalyze pedagogical transformation by challenging and reconstructing teachers' design assumptions, (2) AI tools effectively scaffold specific design tasks when provided with clear parameters, and (3) systematic analysis of student learning evidence creates feedback loops that drive continuous improvement. These interdependent mechanisms form a dynamic system that enables teachers to develop increasingly sophisticated approaches to inquiry-oriented design while maintaining practicality in large-class contexts. The findings offer evidence-based strategies for supporting teacher development in STEM education through synergistic human and technological supports.*
Keywords: learning design; generative AI; learning evidence; teacher professional growth; STEM education

1.引言

在当前推动科学教育高质量发展的背景下，K-12 教师被要求设计并实施具备真实性、思维挑战与学科融合的探究式课程。然而，在实际教学中，由于班级规模大、教学资源有限，教师常常依赖于预设的程序性活动，缺乏深度探究与真实问题解决的元素。如何有效支持教师转变教学观念，提升其课程设计能力，成为亟待解决的问题。学习设计（Learning Design）

作为一个新兴领域，强调通过设计框架和工具支持教师结构化地开展教学设计，提高其教学实践的质量与效率（Mor, Craft & Maina, 2015）。与此同时，生成式人工智能（Generative AI）在教育领域的兴起，为教师提供了实时反馈与辅助设计的新可能（Ogunleye et al., 2024）。本文关注的问题是：在专家和生成式 AI 的支持下，教师如何完成从程序性教学到学习设计师的转型？我们是否可以构建一个可推广的教师成长模型，以系统性支持更多教师向“学习设计师”转变？已有研究表明，教师的课程设计能力并非自发生成，而需要在结构化引导下逐步建构（Laurillard et al., 2013）。学习设计三角框架（LDT）（Law & Liang，2020）被选为本研究的指导框架，因为它与以学生为中心、基于探究的学习设计的核心目标高度契合，并有效解决了教师学习设计实践中的两个主要挑战。LDT 不仅提供了概念上的清晰性，还提供了程序性的支撑，帮助教师通过明确连接学习成果、学科实践和教学方法，设计出连贯的、以探究为导向的课程。LDT 框架基于以结果为导向的方法和 Goodyear（2005）提出的教学设计模型，强调通过将教学意图与设计行动对接，解决设计过程中的矛盾。框架聚焦于三个核心要素：学习成果、学科实践和教学法，它们为课程组件的设计提供了支撑，课程组件通过任务设计帮助学生实现学习成果。为了支持实际应用，LDT 还包含了一个七步设计过程，帮助教师定义学习成果和教学策略、设计与学习成果对齐的课程组件、优化教学策略并监控学习进展。通过这一过程，教师能够发现并解决设计中的常见问题，促进教学设计的连贯性与迭代完善（Law & Liang, 2020）。但专家无法实时提供反馈，而 AI 可以提供更及时的反馈，帮助教师优化活动流程、文本表达，并模拟学生视角审视课程设计。然而，AI 的有效性依赖于教师的提问能力和任务表述的准确性，缺乏人类专家的判断力与整体感知能力。教师若无法清晰表达，AI 的反馈可能会受到限制（Sperling al., 2024）。在此基础上，一些研究提出将学生学习证据纳入教学反馈机制，支持教师对教学设计进行持续优化。然而，如何整合专家支持、AI 协同与学生反馈，形成一个动态互动的成长机制，仍缺乏清晰模型。

2.研究方法

本文采用设计型研究（DBR）方法，对一位中学 STEM 教师的五轮课程迭代过程进行深度追踪。数据包括：课程教案版本、专家反馈访谈、ChatGPT 交互记录、学生作品与过程证据、教师反思笔记。分析聚焦教师在专家—AI—学生三方协同支持下的转型路径，并构建 TEAS 模型。

3.研究结果

本文基于五轮课程迭代实证数据提出“教师—专家—AI—学生学习证据”协同成长模型。

3.1. 模型构建的实证支撑

3.1.1. 教师的迭代设计与角色转型

教师在五轮课程迭代中逐步从程序性教学向探究导向教学转型，表现在教学目标、流程、证据收集与反思内容的不断演进。

轮次	教学目标	学习流程	学习证据	教师反思
1.0	以内容为核心（动手实践）	思考问题 ➜ 观看示范 ➜ 小组制作 ➜ 分享展示	实践作品	程序性教学
2.0	内容+探究要素并存	提出假设 ➜ 实践 ➜ 讨论验证	实践+过程片段记录	明确课程定位

轮次	教学目标	学习流程	学习证据	教师反思
3.0/4.0	知识+探究路径系统整合	问题生成 ➜ 控制变量 ➜ 设计实验 ➜ 得出结论	探究日志+作品	科学化教学流程
5.0	融入科学思维与价值导向	自主提出问题 ➜ 完整实验设计 ➜ 多轮修正	探究报告+自评互评	完善的探究体系

3.1.2. 专家支持机制

专家反馈主要聚焦在“目标澄清—任务定位—证据意识”三个层面，通过教学诊断与反思引导，促发教师在结构层面对课程进行重构。比如：“专家提醒我要‘拆分教学目标，并按照科学探究流程来设计学习活动’，这让我意识到任务设计还不够清晰。”

3.1.3. AI 协同特征的演进

在专家引导下，教师逐渐学会提出结构化问题，AI 反馈从泛化建议逐步过渡为流程生成、评价设计等专业支持。

阶段	教师提问	AI 反馈类型	示例
初期	“你觉得这课怎么样？”	鼓励性反馈	“这个教案设计非常有趣且富有探索性。”
中期	“我希望引导学生控制变量，有建议吗？”	结构化建议（引导语/流程图）	“可以设置不同的任务难度层次，帮助学生理解变量控制。”
后期	“请优化我的教学步骤并补充评价方案。”	完整任务序列+评价表设计	“我将基于探究步骤优化流程，并附上每阶段的自评互评标准……”

3.1.4. 学生学习证据的反馈作用

学生学习表现为教师调整教学设计提供了重要反馈信号，是课程持续优化的中介变量。

轮次	证据表现	教师调整点
1.0	模仿性完成任务	增加开放问题，引导学生提问
3.0	假设不清、变量不控	引入案例教学，强化实验结构
5.0	能进行互评与模型修正	鼓励学生自建流程、自主追问

3.2. 专家—AI—教师—学生的三类协同路径机制

在模型运行过程中，四类要素之间呈现出三种典型的动态交互路径，构成“诊断—设计—验证—再设计”的螺旋式协同机制。

3.2.1. 专家驱动路径

专家 ➜ 教师 ➜ AI ➜ 学生：专家提出教学目标重构建议，教师基于此向 AI 寻求支持，AI 提供方案优化教学流程，学生学习产出反馈新的问题。

实证示例：在 1.0 版本课程实施后，专家通过分析教师反思指出，课程可定位为“科学探究 + 工程实现”。教师据此向 AI 提问：“如何让我的设计更加具有探究性？”AI 建议采用问题驱动的方式构建课程结构。由此，2.0 版本的学习路径围绕两个核心问题展开，显著增强了探究导向。学生在任务完成过程中表现出良好思维状态，并提出了如“为什么增加重量后系统会平衡？”等具有深度的问题。教师首次在课堂中面临高质量学生提问，一时间未能及时回应，这一情境反向推动教师重新思考师生互动与教学应答策略。

3.2.2. 学生证据驱动路径

学生 ➜ 教师 ➜ AI ➜ 专家：学生产出暴露教学短板，教师反思后利用 AI 初步调整，专家再提供精准化建议，形成基于证据的反向优化机制。

实证示例： 在第 2.0 版本实施过程中，学生提出关于系统平衡的问题，教师一时难以作答，转而借助 AI 检索资料补充相关知识，由此意识到自身在 STEAM 课程中存在知识短板。经过与专家深入交流，专家指出症结在于教学目标的拆解不够细致，导致知识结构松散，教师难以建立本节课的知识网络图。随后教师据此重新梳理知识结构，并结合 AI 支持完善教学设计，从而提升了应对复杂项目式学习情境的专业胜任力。

3.2.3. AI 驱动路径

AI ➞ 教师 ➞ 专家 ➞ 学生：教师预先调用 AI 生成教学方案，筛选后实施教学，专家结合学生学习证据进行评估，反馈结果反哺设计。

实证示例： AI 在第 4 轮之后建议教师“可以加入如何通过实验数据进行定量分析的要求”，教师根据实际情况，拒绝了 AI 的建议。同时 AI 提出在自评和互评阶段“可以加入具体的评估标准，指导学生如何评价他人作品”，教师采纳了 AI 建议，并和专家沟通后，在 5.0 版本的中，加入自评和互评表格。

4.讨论与结论

本研究通过分析五轮迭代过程，研究发现，该转型依赖于专家引导的认知重构、AI 辅助的精细化设计以及基于学生学习证据的迭代优化三大关键要素。专家支持在教师转型中发挥了结构性作用。与既有研究中学习设计框架的应用类似（Mor & Craft, 2012），本研究发现专家通过帮助教师识别核心问题、诊断系统性设计缺陷，并引导结构化反思，促进了教师从“活动执行者”到“学习设计师”的认知转变。协助教师澄清学习目标，还推动其建立更严谨的设计逻辑，这与学习科学领域强调的“教师作为设计思维实践者”的定位一致（Kali et al., 2015）。生成式 AI 的辅助功能呈现显著的“任务依赖性”。尽管 AI（如 GPT）能够快速生成活动设计细节或优化特定环节（如评价标准），但其有效性高度依赖于教师输入的精确性。当教师提出泛化问题时，AI 仅能提供微调建议（如调整措辞）；而当教师明确设计需求时（如“设计一个聚焦数据解释能力的评价量表”），AI 的生成质量显著提升。这一发现呼应了近期关于“教师需培养 AI 提示工程能力”的讨论（Luckin et al., 2022），也揭示了当前 AI 工具的局限性——它更擅长增量改进而非颠覆性创新。生成式 AI 的有效性则依赖于教师输入的精准度，能够根据明确需求优化设计，但在泛化问题上效果有限。学生学习证据的作用则需教师具备数据素养，能够通过分析转化为设计洞察。实践启示包括：专家-AI 协同模式可聚焦宏观设计与实施分工，教师需加强 AI 提示工程和学习分析培训，学校应建立“设计-实施-评估”的迭代制度。未来研究可进一步探讨不同教师经验水平与 AI 工具适应性。未来可拓展多样教师样本，检验模型在不同阶段、学科的适应性，并进一步开发校本 AI 支持工具，助力教师持续成长。

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