Received: 26 March 2022 | Accepted: 29 July 2022

DOI: 10.1111/bjet.13267

ORIGINAL ARTICLE

British Journal of Educational Technology BERA

Fostering low-achieving students' productive disciplinary engagement through knowledge-building inquiry and reflective assessment

Yuqin Yang[1] | **Kaicheng Yuan[1]** | **Xueqi Feng[2]** | **Xiuhan Li[1]** | **Jan van Aalst[3]**

[1]Faculty of Artificial Intelligence, Central China Normal University, Wuhan, China

[2]Center of Studies for Future Education, Southern University of Science and Technology, Shenzhen, China

[3]Faculty of Education, The University of Hong Kong, Pok Fu Lam, Hong Kong

Correspondence

Xiuhan Li, Central China Normal University, Wuhan, China.
Email: xiuhanli@ccnu.edu.cn

Funding information

National Natural Science Foundation of China, Grant/Award Number: 62107020; Ministry of Education of the People's Republic of China, Grant/Award Number: 21YJA880078; Central China Normal University, China, Grant/Award Number: CCNUTEIII 2021-11

Abstract

Supporting productive disciplinary engagement (PDE) in low-achieving students is an important but challenging goal in education. This study used a knowledge-building inquiry approach augmented by reflective assessment to facilitate low-achieving students' PDE. A quasi-experimental design method was employed to examine the effects of reflective assessment in supporting low-achieving students' PDE. The experimental class of tenth graders (n = 20) conducted inquiries in the visual arts in a knowledge-building design augmented by reflective assessment, while the comparison class of tenth graders (n = 14) conducted inquiries in a regular knowledge-building design without reflective assessment. This study lasted approximately 4 months and the primary data source was the online discourse. A comparative analysis of the knowledge-building discourse characteristics and the sequential patterns of the discourse moves revealed higher cognitive, emotional and epistemic engagement in the experimental class compared with the comparison class. Epistemic network analysis showed that reflective assessment facilitated low-achieving students' collective reflection, monitoring and regulation, as shown by their metacognitive discourse moves. Their metacognition further helped them to achieve higher levels of cognitive, emotional and epistemic engagement than the comparison class. This study provides insights into the connections between inquiry, engagement and assessment. Moreover, it has implications for designing technology-supported collaborative inquiry environments to support low-achieving students' engagement and higher-level skills.

KEYWORDS
knowledge building, low-achieving students, metacognition, productive disciplinary engagement, reflective assessment

Practitioner notes

What is already known about this topic

- Supporting low-achieving students' productive disciplinary engagement (PDE) is an important but challenging goal in education and limited research has focused on it.
- Knowledge-building inquiry design augmented by reflective assessment is promising in supporting low-achieving students' PDE.
- Little research has examined the effects of reflective assessment-augmented knowledge building inquiry on low-achieving students' PDE and the mechanism through which reflective assessment supports their PDE.

What this paper adds

- Reflective assessment-augmented knowledge-building inquiry is effective in supporting low-achieving students' PDE.
- Portfolio-supported Reflective assessment in Knowledge Forum facilitated low-achieving students' enactment of collective reflection, monitoring and regulation, and these metacognitive processes further helped low-achieving students to achieve higher levels of cognitive, emotional and epistemic engagement.
- This study provides insights into the connections between inquiry, engagement, and assessment.

Implications for practice and/or policy

- It is crucial to create a collaborative and reflective community culture to help low-achieving students gradually gain agency.
- It is critical to help low-achieving students to develop a productive belief that idea improvement and reflection is a continuous and iterative process.
- The effectiveness of reflective assessment requires face-to-face knowledge-building discussion and collaborative reflection opportunities scaffolded by assessment tools and analytics that encourage low-achieving students to engage in meta-level discussion.

INTRODUCTION

Helping students develop productive disciplinary engagement (PDE) is one of the focuses of learning sciences research. PDE involves students collaboratively making "intellectual progress" on real disciplinary problems using ideas, discourses and practices associated with a given discipline (Engle, 2012; Engle & Conant, 2002; Jordan et al., 2021). Supporting students' PDE enables them to better understand disciplinary knowledge and practices and develop higher-level skills, such as collaboration and coordination, agency and knowledge creation. The development of these skills is critical to students' academic performance and continual life-long development (Becker & Luthar, 2002; Snell & Lefstein, 2018; Yang, van Aaslt, et al., 2020). Therefore, all students, particularly low-achieving students, need to be provided with opportunities to develop PDE. However, low-achieving students usually do not have equitable access to such opportunities, as teachers typically have low expectations regarding low-achieving students' performance (Zohar & Dori, 2003) and thus provide them with instructional approaches and opportunities associated with lower-level skills (Yang, van Aaslt, et al., 2020).

Knowledge building, a computer-supported collaborative inquiry model, is promising in fostering students' PDE, including low-achieving students (eg, Chen, 2017; Tao & Zhang, 2021; Yang, van Aalst, et al., 2020; Zhang et al., 2018). Knowledge building emphasizes the advancement of knowledge frontiers through the development of collective responsibility (Scardamalia, 2002; Scardamalia & Bereiter, 2014). Knowledge-building inquiry environments enable students to engage in inquiry-oriented disciplinary practices to investigate authentic problems, establish community norms, construct a joint problem space, negotiate and coordinate ideas, maintain collaborative dynamics, and collectively advance disciplinary ideas (Scardamalia, 2002; Scardamalia & Bereiter, 2014), which are crucial for fostering students' PDE. Productive knowledge-building inquiry requires students to exhibit epistemic dispositions (Yang, Chen, et al., 2020), quality social interactions (Barron, 2003; Stahl, 2006; Yang, van Aalst, et al., 2020), and metacognitive awareness and skills (eg, goal setting, monitoring, and reflection; Bransford et al., 1999; Brown, 1997; Järvelä et al., 2015; White & Frederiksen, 2005). However, low-achieving students struggle to exhibit the above characteristics and therefore need appropriate scaffolding strategies to fully benefit from knowledge-building.

Reflective assessment is a type of student-directed assessment that engages students in metacognitive cycles of goal setting, monitoring, reflection, and regulation. It is an effective strategy for scaffolding low-achieving students' engagement in knowledge-building inquiry (White & Frederiksen, 1998; Yang, 2019; Yang et al., 2016; Yang, van Aalst, et al., 2020). This study designed a reflective assessment-augmented knowledge-building inquiry environment to facilitate low-achieving students' PDE. To promote low-achieving students' effective reflective assessment, we adapted knowledge-building principles to scaffold their construction of electronic portfolios. Two groups of 10th-grade low-achieving students enrolled in a visual arts class participated in this study. This study examined the effects of knowledge-building inquiry and portfolio-supported reflective assessment on low-achieving students' PDE, and the mechanism through which reflective assessment facilitates their PDE.

LITERATURE REVIEW

Low-achieving students and PDE

Low-achieving students are often disengaged from their schoolwork and have literacy challenges and learning difficulties (Shen et al., 2007). They also often encounter problems in communication and coordination with peers, and in metacognition and regulation activities, such as the use of low-level metacognitive strategies, and in planning, monitoring and regulating learning tasks, outcomes and processes (Azevedo et al., 2004; van Aalst, 2009). Moreover, low-achieving students exhibit negative attitudes toward learning and are more likely than other students to experience negative academic emotions such as frustration and boredom (Lee et al., 2016; Yang, 2019). Helping low-achieving students develop PDE, which involves students improving their disciplinary understanding and high-level skills, remains a challenge for teachers and researchers. Interventional studies on low-achieving students have focused on their task engagement and aimed to improve their academic achievement (Baxter et al., 2001; Dietrichson et al., 2017; Han et al., 2015). However, few PDE studies have aimed to scaffold low-achieving students' higher-level skills and disciplinary understanding.

PDE was established by Engle and Conant (2002) and is focused on guiding students to appropriate disciplinary ideas and practices to address disciplinary problems, and thereby advance intellectually (Engle, 2012). PDE is a contextualized, dynamic, shared and multi-faceted concept (Engle, 2012; Gomoll et al., 2017; Jordan et al., 2021; Sinha et al., 2015). It typically involves behavioural dimensions (eg, on-task participation and behaviour), cognitive dimensions (eg, the development of understanding and the use of high-level strategies) and emotional dimensions (students' interests and attitudes) (Fredricks et al., 2004; Sinha et al., 2015). PDE recursively affects sustained knowledge-building inquiry and knowledge creation via on-topic participation and persistence (behavioural engagement), productive collaboration and coordination (cognitive engagement), positive academic emotions (emotional engagement) and the use of disciplinary ideas, discourse, practices and tools to address meaningful disciplinary problems (epistemic engagement).

Low-achieving students are usually considered incapable of PDE in collaborative and reflective inquiry that requires the cultivation of students' higher-level skills. Several studies have shown that providing low-achieving students with access to collaborative and reflective inquiry based on appropriating scaffoldings—for example, appropriating project activities and tools to challenge traditional classroom roles, incorporating authentic problems and productive social interactions, and building knowledge—can enable them improve their disciplinary understanding and high-level skills (Calabrese Barton & Tan, 2010; Dietrichson et al., 2017; Raes et al., 2014). This recognizes that low achievement is more of an artefact of learning design than a psychological trait. To foster PDE, Engle and Conant (2002) proposed four design principles for facilitating students' learning of environment design: problematizing disciplinary concepts, giving students the agency to address learning-related problems, holding students accountable for making intellectual progress and contributing to knowledge construction, and providing scaffoldings and resources that students need for productive engagement. The current study leverages the above principles to design a knowledge-building inquiry environment for low-achieving students.

Reflective assessment-augmented knowledge-building inquiry model for low-achieving students' PDE

This study is based on the knowledge-building inquiry model (Scardamalia & Bereiter, 2014). Knowledge building is characterized by a trajectory of open-ended idea improvement through students' collective responsibility and epistemic agency in co-configuring collaborative dynamics and co-directing scientific inquiry (Scardamalia, 2002; Scardamalia & Bereiter, 2006, 2014). Knowledge building is based on the notion of scientific communities (Bereiter et al., 1997) and aims to engage students in knowledge-building related activities, as demonstrated by scientists who progressively extend existing knowledge rather than seek a static source of "truth" (Bereiter et al., 1997). Knowledge-building therefore aims to fundamentally transform education by cultivating communities in which members collaborate to advance collective knowledge (Scardamalia, 2002; Scardamalia & Bereiter, 2014). Knowedge-building discourse that is at the heart of knowledge building model most typically takes place on Knowledge Forum®. Knowledge Forum is an online platform that has been developed to support the activities of creative communities. Features of Knowledge Forum are designed to facilitate students to conduct sustained disciplinary inquiries, and reframe and improve community ideas. For example, the "reference" and "rise-above" functions allow students to use peers' notes as references when write a note, and thereby progressively synthesize and rise above community's ideas as their work proceeds. Furthermore, a suite of assessment tools are integrated into Knowledge Forum to help students assess the status of their participation, interaction and knowledge-building discourse. For example, the Social Network Analysis (SNA) applet can generate sociograms that visualize reading and build-on activity and calculate the corresponding network densities.

Low-achieving students often encounter problems such as unproductive collaborations and social interactions, and inability to implement high-level cognitive and metacognitive strategies in planning, reflecting and regulating their learning and inquiry. Therefore, they encounter problems during knowledge building and other inquiry exercises (van Aalst, 2009; Yang, van Aalst, et al., 2020). It is thus necessary to provide low-achieving students with appropriate learning design and scaffoldings to support their PDE. In this study, we briefly explain four knowledge-building principles critical for scaffolding low-achieving students' PDE: (i) *Epistemic agency*: This involves low-achieving students assuming high-level responsibilities associated with shared goals, evaluations, emotions and long-range planning. This is distinct from non-PDE situations, in which such responsibilities are assumed by teachers. (ii) *Community knowledge*: This involves demographic participation, the contribution of diverse and valuable ideas, and the advancement of frontiers of community knowledge. (iii) *Idea improvement*: This is associated with the developmental nature of knowledge and ideas. That is, it involves low-achieving students continually and collaboratively deepening their inquiries and improving the coherence, quality and utility of their ideas and discourse. (iv) *Embedded and transformative assessment*: This emphasizes the way in which assessment is integrated into knowledge building, given that assessment is a learning process. Accordingly, low-achieving students can reflect on and regulate their knowledge-building inquiry through assessment.

Reflective assessment aligns with the knowledge-building principle of "embedded and transformative assessment." It involves students taking collective agency to set inquiry goals, monitor personal and community progress, use feedback to identify knowledge gaps, and examine how to improve their ongoing inquiry and address broader problems (Scardamalia, 2002; White & Frederiksen, 1998; Yang, van Aalst, et al., 2020). Thus, reflective assessment enables students to increase their metacognitive awareness, actualize their metacognitive skills, and co-design and co-direct their ongoing inquiry and learning via metacognitive cycles of task analysis, monitoring, reflection and inquiry regulation (Yang, Chen, et al., 2020; Yang, van Aalst, et al., 2020).

Research on reflective assessment enhanced with student-directed electronic portfolios in knowledge-building classrooms has revealed the positive effects of reflective assessment on students' domain understanding and productive knowledge-building discourse (Lee et al., 2006; Lei & Chan, 2018, van Aalst & Chan, 2007; Lei & Chan). However, the effects of portfolio-supported reflective assessment on low-achieving students' PDE and the mechanism through which reflective assessment supports their PDE have not been investigated. Our previous studies have examined reflective assessment using analytics that encourage secondary school low-achieving students to collectively increase their metacognition (Yang, 2019; Yang et al., 2016; Yang, van Aalst, et al., 2020). These studies have revealed the scaffolding function of reflective assessment—helping students to engage in productive knowledge-building inquiry and develop higher-order skills.

The current study

In the current study, we designed a portfolio-supported reflective assessment process integrated with knowledge-building inquiry to support low-achieving students' PDE. We also used knowledge-building principles to facilitate low-achieving students' engagement in productive electronic portfolios. The current study aimed to examine the effects of reflective assessment-augmented knowledge-building inquiry on low-achieving students' PDE and the mechanism through which reflective assessment supports their PDE. We aimed to answer the following research questions.

1. RQ1: Do low-achieving students who engage in reflective assessment-augmented knowledge-building inquiry (the experimental class) exhibit higher PDE than those who engage in regular knowledge-building inquiry (the comparison class)?
2. RQ2: How does reflective assessment support low-achieving students' PDE?

METHODS

Research contexts and participants

In Hong Kong's secondary schools, students are divided into three groups—Band 1 (the highest-achieving group), Band 2 (the average-achieving group), and Band 3 (the lowest-achieving group)—based on the results of public examinations taken at the end of 6th Grade. This study was conducted at a Hong Kong Band-3 secondary school, and the participants were two 10th Grade classes studying Visual Arts that had performed at or below the 10th percentile of the student population in the 6th Grade examination, and were thus recognized as low-achieving students. In this study, the participants studied the topic of "Design and environment conservation" over 4 months, which comprised three lessons per week (one on painting and two on knowledge-building work). A quasi-experimental approach was used: an experimental class of 20 participants worked in a knowledge-building environment augmented by portfolio-supported reflective assessment, and a comparison class of 14 participants worked in a regular knowledge-building environment without portfolio-supported reflective assessment. The participants had no previous knowledge-building experience, whereas the teacher was an expert in using knowledge-building inquiry models to motivate participants and had used the knowledge-building inquiry model in teaching for several years.

Designing the knowledge-building inquiry environment enriched by reflective assessment (experimental class)

We collaborated with the course instructor to design a three-component knowledge-building environment enriched by portfolio-supported reflective assessment in Knowledge Forum. This design was adopted from the earlier study by Chan (2011) and refined for the participants by including an emphasis on the four knowledge-building principles: epistemic agency, community knowledge, idea improvement, and embedded and transformative assessment.

The course began with the teacher's *cultivation of a collaborative and reflective culture to help students develop knowledge and skills needed for PDE* (Component 1, weeks 1–10). The students studied the topic of how design can be used to support environmental conservation, and engaged in a set of agency-driven activities involving small group collaborations, whole-class discussions and collaborations, and individual reflection. For example, to develop collaboration skills and basic disciplinary understanding, small groups of the students (4–5 students) were first required to construct collaborative concept maps (Figure 1), and then the whole class investigated lines of inquiry and generated ideas that they incorporated into a knowledge-building Wall for presentation to the public. The students also conducted investigations on how to conserve environment through interviewing relevant individuals (eg, officials responsible for environmental conservations, scholars researching how to use design to support environmental conservations), and made field trips to museums and other institutions.

Next, the participants were encouraged to *address authentic problems in design and environmental conservation and progressively improve idea-centred discourse in a Knowledge Forum* (Component 2, weeks 11–13). Thus, the participants built on the discussions that had informed the development of the knowledge-building wall to formulate higher-level explanation-seeking questions for further inquiry on the Knowledge Forum (Figure 1), by assessing exemplar questions and reflecting on the assessment criteria. The participants also engaged in explanation-oriented discourse, reflecting on notes and assessment criteria for productive discussion threads in regular face-to-face knowledge-building talks. In addition, the participants used weekly analytic data generated by assessment tools embedded in Knowledge Forum to reflect on their own participation, social interactions, and contributions. These disciplinary inquiries, practices and reflections enabled the participants to develop a sense that their ideas were improvable and that their community played an important role in supporting this improvement.

Finally, after engaging in knowledge-building work for approximately 3 weeks, the participants *engaged in portfolio-supported reflective assessment to further support their PDE* (Component 3, weeks 14–17). In this assessment, the participants were required to select at least five notes written by community members and five notes written by themselves, use knowledge-building principles to analyse the weaknesses and strengths of these notes, and then write a reflective statement to show how and why the notes supported their theories on how design contributes to sustainable development. In doing so, the participants reviewed what they had learned, monitored their learning process, reflected on their knowledge-building inquires and discussions, identified core problems for further inquiry, extended their understanding, and created new theories. The participants were encouraged to construct and improve their portfolios until the end of the course, and were provided with participation and interaction data each week.

Instruction in the comparison class

The comparison class engaged in the same activities as the experimental class for Components 1 and 2. However, in Component 3, the comparison class continued to participate and write notes in a Knowledge Forum.

Data sources and analysis

We used 305 Knowledge Forum notes from the experimental class and 138 notes from the comparison class to examine the participants' PDE. We posited that the participants' PDE would reflect their improvement in knowledge-building discourse, as this discourse can demonstrate low-achieving students' PDE across cognitive, emotional and epistemic aspects, in addition to their use of metacognition.

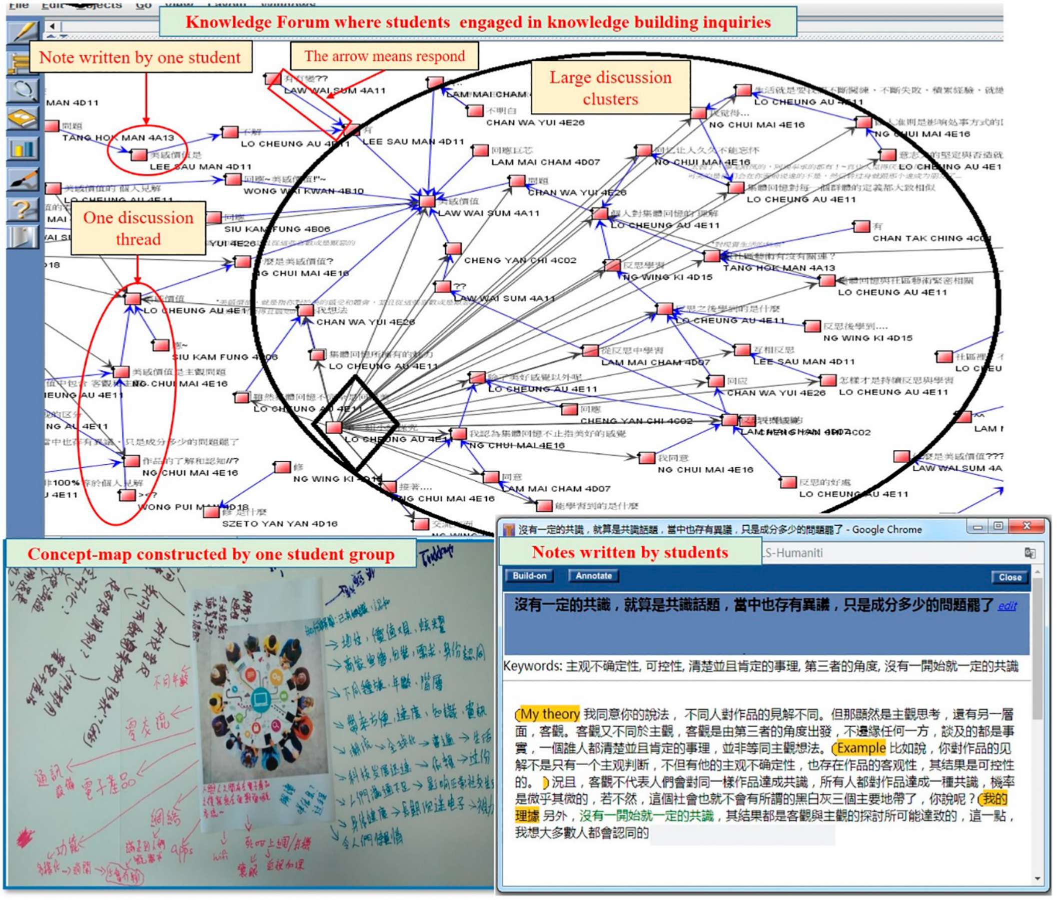


FIGURE 1 Knowledge Forum platform (top), note contributed by one student (bottom right) and one concept map (bottom left).

We pre-processed the Knowledge Forum notes by sorting them into discussion threads, where a discussion thread is a group of notes that address the same principal problem (Zhang et al., 2007). This allowed us to obtain a good understanding of the participants' work, and also provided categorized material for subsequent content analysis, lag sequential analysis and epistemic network analysis. The first author sorted the 305 notes (experimental class) and 138 notes (comparison class) into 12 and 8 threads, respectively. Table S1 in the supplementary file presents the thread analysis results.

Low-achieving students' PDE is manifested by their knowledge-building discourse moves

To answer RQ1, we first conducted content analysis of the notes in each discussion thread to qualitatively characterize the participants' PDE. We developed a coding framework based on previous work by D'Mello and Graesser (2012), Pekrun et al. (2017), Yang (2019) and Yang et al. (2022) (Table S2 in the supplementary file). The coding framework features four categories: cognitive engagement, emotional engagement, epistemic engagement, and metacognition/metadiscourse. Two raters, the first author and another researcher with a PhD degree and experience in qualitative discourse analysis, independently coded 130 notes from the experimental class (n = 130, >30%). The inter-rater consistencies were 92% for cognitive engagement, 94% for emotional engagement, 96% for epistemic engagement, and 99% for metacognition/metadiscourse.

Next, to examine the differences between the experimental and comparison students' PDE, we conducted two comparisons using our content analysis results. First, we examined the differences in the frequency distribution of discourse moves by conducting a chi-square test using SPSS Statistics 21. Because we focused on PDE productivity, we only calculated the higher-level discourse moves (eg, "engaging problem-centred idea uptake," "joy," "explanatory questions," and "reflecting and deepening inquiry"). Second, we used lag sequential analysis to examine the differences between the experimental and comparison classes in sequential contingencies of discourse moves in PDE (Bakeman & Gottman, 1997). We posited that sequential patterns observed in discourse would illustrate the differences in the three dimensions of PDE. We used the Sequences Package for R to conduct a lag sequential analysis, and used the z-scores to calculate the number of times a code (ie, one type of discourse moves) transitioned directly to another code, and z-scores above 1.96 were considered to indicate a significant transition sequence between two codes (Bakeman & Quera, 2011).

Portfolio-supported reflective assessment facilitates low-achieving students' PDE

To answer RQ2, we examined the differences between the epistemic network characteristics of the experimental class and the comparison class. We posited that portfolio-supported reflective assessment helps low-achieving students to deploy and develop their metacognition (eg, monitoring, reflecting, and regulating) in knowledge-building inquiries in the form of metadiscourse, and that metacognition helps them to engage in higher-level discourse moves. These epistemic networks can demonstrate the stronger connections between discourse moves that indicate metacognition, and higher-level discourse moves that indicate the cognitive, emotional and epistemic aspects of low-achieving students' PDE.

To examine the differences between epistemic network characteristics, we conducted an epistemic network analysis (Shaffer, 2017) using the epistemic network analysis Web Tool (www.epistemicnetwork.org). The epistemic network analysis algorithm of this tool identifies and calculates connections between coded elements in data and visualizes them in dynamic network models, which illustrate the structure and strength of connections between coded elements by quantifying the co-occurrences of codes within a defined segment of data.

RESULTS

Effects of reflective assessment-augmented knowledge-building inquiry on low-achieving students' PDE

Classroom differences in discourse-move characteristics (comparison 1)

Table 1, on the basis of content analysis results presented in Table S3 in the supplementary file, shows that the frequency distributions of higher-level discourse moves were different for each class: the experimental class had more higher-level discourse moves than the comparison class. A subsequent chi-square test revealed that these differences were statistically significant, χ^2 (df = 1, N = 1129) = 8.95, p < 0.05. Primarily, the experimental class went further in developing and extending their problem-centred ideas and collective ideas compared than

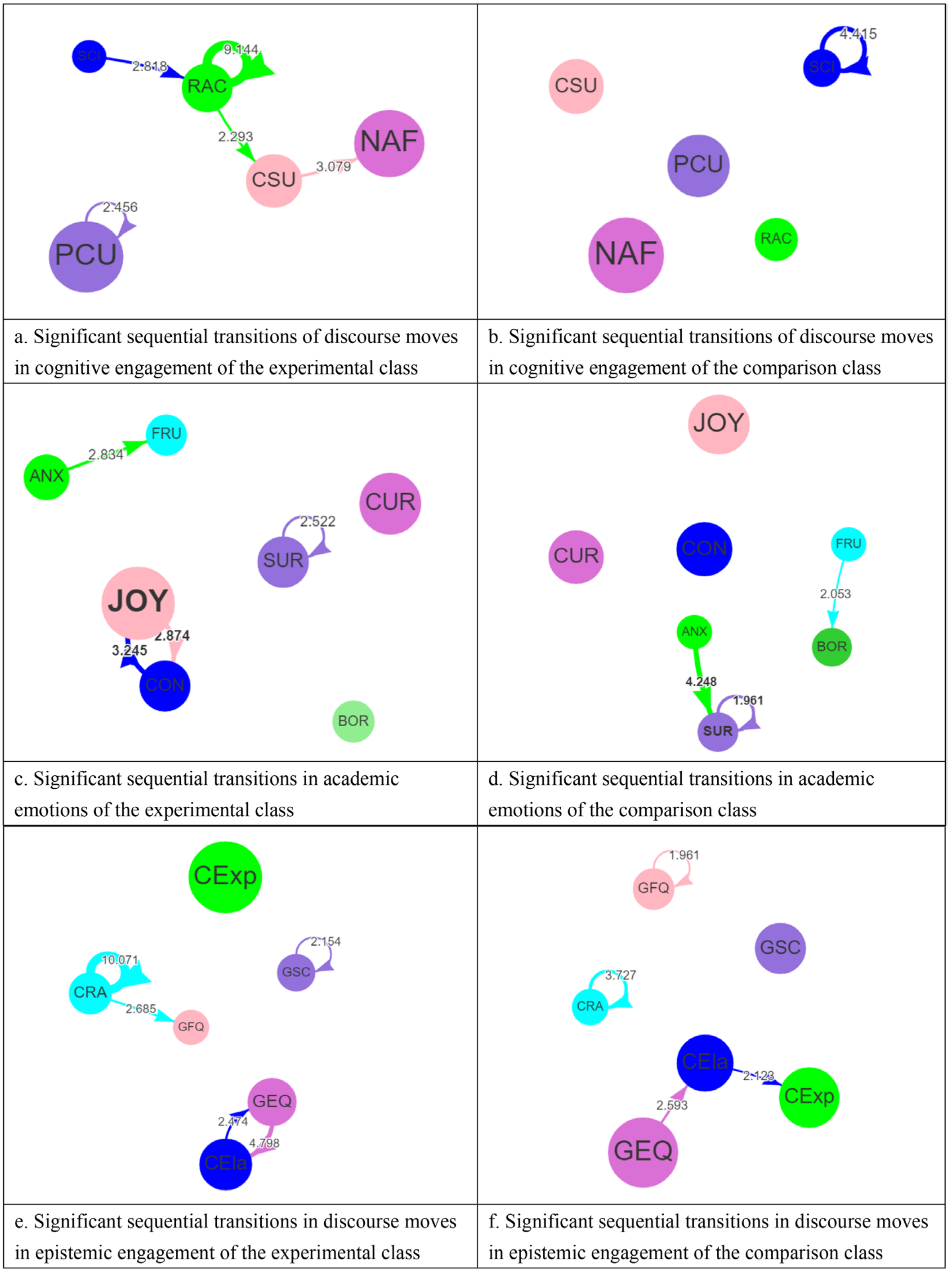
TABLE 1 Differences between the two classes' discourse-move characteristics

			Experimental class		Comparison class	
	Level	Abbreviation	*f*	% (f/305)	*f*	% (f/138)
Cognitive engagement						
Creating shared understanding	Low	CSU	45	14.75	14	10.14
Negotiating a fit	Low	NAF	90	29.51	43	31.16
Engaging problem-centred idea uptake	High	PCU	92	30.16	24	17.39
Summarizing community ideas	High	SCI	5	1.64	2	1.45
Rising above community ideas	High	RAC	9	2.95	0	0.00
Emotional engagement						
Joy	High	JOY	142	46.56	52	37.68
Curiosity	High	CUR	68	22.30	32	23.19
Surprise	High	SUR	31	10.16	9	6.52
Confusion	Neutral	CON	33	10.82	31	22.46
Anxiety	Neutral	ANX	24	7.87	3	2.17
Frustration	Low	FRU	5	1.64	3	2.17
Boredom	Low	BOR	2	0.66	8	5.80
Epistemic engagement						
Generating fact-seeking questions	Low	GFQ	9	2.95	9	6.52
Generating explanatory questions	High	GEQ	65	21.31	48	34.78
Generating a simple claim	Low	GSC	18	5.90	24	17.39
Contributing an elaboration	Low	CEla	78	25.57	30	21.74
Contributing an explanation	High	CExp	129	42.30	26	18.84
Contributing a rise-above note	High	CRA	14	4.59	3	2.17

the comparison class. The experimental class was also more likely than the comparison class to experience positive epistemic emotions such as surprise and joy. Furthermore, the experimental class engaged in more explanation-oriented inquiry than the comparison class. These results show that the experimental class demonstrated higher cognitive engagement, emotional engagement, and epistemic engagement than the comparison class, which illustrates the positive effects of reflective assessment-augmented knowledge-building inquiry on low-achieving students' PDF.

Differences between the two classes' sequential transitions of discourse moves (comparison 2)

To further reveal the effects of reflective assessment-augmented knowledge-building inquiry on students' PDE, we examined the sequential transitions of discourse moves in each classes' cognitive, emotional and epistemic engagement. We used Viswork Package for R to identify the significant sequential transitions (see Figure 2) on the basis of the adjusted residuals (see Tables S4–S6 in the supplementary file). Only the sequences with a *z*-score greater than 1.96 are shown in Figure 2, where the higher the *z*-score, the stronger the link between nodes. The sizes of the nodes denote the frequency of each discourse move in each class, where larger nodes represent greater frequency.



a. Significant sequential transitions of discourse moves in cognitive engagement of the experimental class

b. Significant sequential transitions of discourse moves in cognitive engagement of the comparison class

c. Significant sequential transitions in academic emotions of the experimental class

d. Significant sequential transitions in academic emotions of the comparison class

e. Significant sequential transitions in discourse moves in epistemic engagement of the experimental class

f. Significant sequential transitions in discourse moves in epistemic engagement of the comparison class

FIGURE 2 The significant sequential transitions of discourse moves in the experimental and comparison classes. See the abbreviations in Table 1.

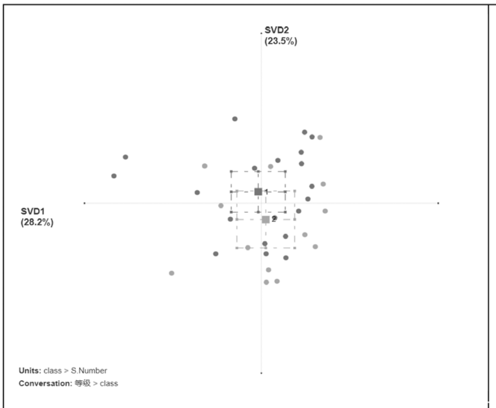
Figure 2 shows the transition of discourse moves in the experimental and comparison classes, which reveals that the experimental class displayed more productive sequential transition patterns of discourse moves in cognitive engagement than the comparison class. For example, the experimental class exhibited five productive significant sequences in cognitive engagement: SCI→RAC (2.82), RAC→RAC (9.14), RAC→CSU (2.93), CSU→NAF (3.08), and PCU→PCU (2.46). These results suggest that the experimental class progressively deepened its knowledge-building inquiries and fostered ideas during several rounds of negotiating meanings among diverse ideas, uptake of ideas, summarizing and rising above community ideas. The experimental class also exhibited more productive significant transitions in emotional engagement such as SUR→SUR (2.52), JOY → CON (2.87) and CON → JOY (3.25), and transitions in epistemic engagement such as CEla → GEQ (2.47), GEQ→CEla (4.80), CRA→CRA (10.07), and CRA→GEQ (2.69). These results suggest that the experimental class exhibited productive emotion transitions and therefore productive emotional engagement. These results also suggest that the experimental class engaged in productive cycles of generating explanatory questions-contributing explanations-rising above ideas and therefore manifested productive epistemic engagement. Overall, these results illustrate the positive effects of reflective assessment-augmented knowledge-building inquiry on low-achieving students' PDE.

Reflective assessment in facilitating low-achieving students' PDE

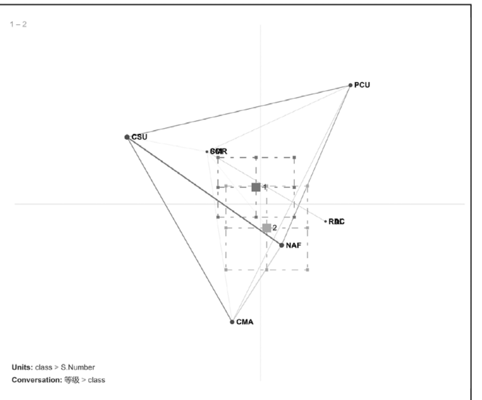
We used epistemic network analysis to examine the connections between discourse moves indicating students' metacognition and discourse moves indicating their cognitive engagement, emotional engagement and epistemic engagement. Figure 3 displays a plot of connections of the discourse moves of the experimental class and the comparison class, and the subtracted epistemic network of the two classes. The different coloured dots represent the centroids of each participant in the experimental class and the comparison class, respectively, and the mean centroids of all dots in each class are shown as squares, with a 95% confidence interval for each dimension represented by the rectangular outline (see Figure 3a,c,e).

Figure 3a presents the plot of connections between the discourse moves of the experimental and comparison classes, showing the significant differences between the means for each class along the *x*- and *y*-axis. However, the independent-sample *t*-tests (assuming unequal variances) of the mean centroid values were not significantly different between the two classes. We also constructed the subtracted network depicted in Figure 3b—by subtracting the mean connection strengths for the participants in the comparison class from the mean connection strengths for participants in the experimental class—to examine salient connections that contributed to the differences between the two classes. The darker, thicker lines indicate greater connection strength, which reveals that there were more connections made by the experimental participants than the comparison participants to the PCU (engaging problem-centred uptake) and CMA (creating metacognitive awareness) nodes. This suggests that links between metacognitive discourse moves and higher-level cognitive discourse moves, and between the higher-level discourse moves PCU and RAC, were prominent features of the experimental class.

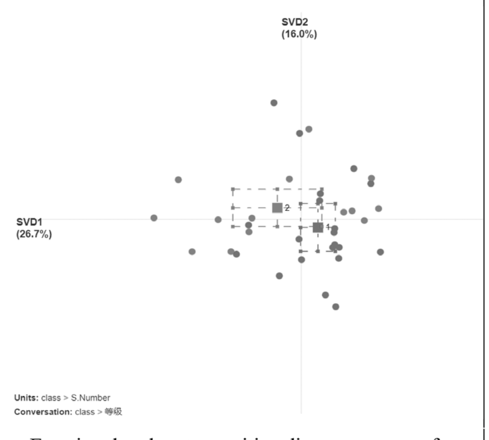
Figure 3c presents a plot of an epistemic network analysis of the experimental and comparison classes' emotional and metacognitive discourse moves, which indicates the differences between the two classes. The independent-samples *t*-test (assuming unequal variances) of the mean centroid values shows that this difference was significant along the *x*-axis, (t [17.25] = 1.83; $p < 0.05$; and $d = 0.71$), suggesting that the two classes each had significant connection patterns. Figure 3d depicts the corresponding subtracted network, which reveals



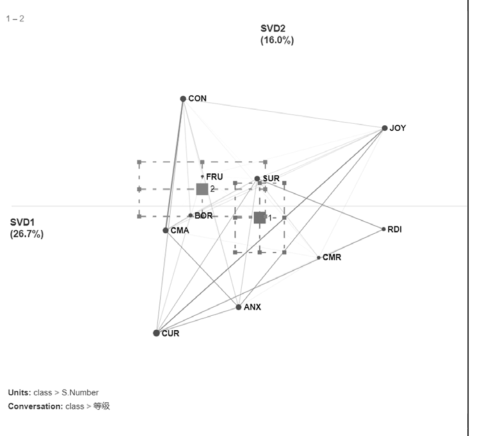
a. Cognitive and metacognitive discourse moves for the experimental class (purple) and comparison class (green) represented by points and centroids



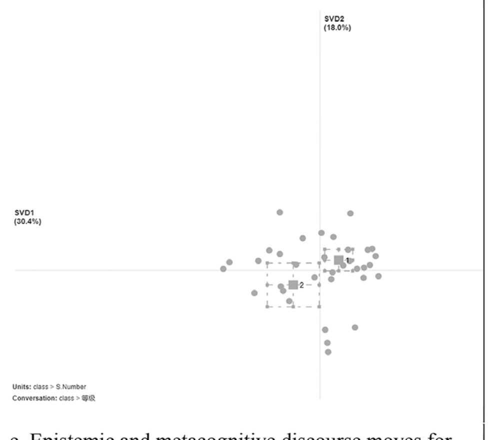
b. Subtracted epistemic network of cognitive and metacognitive discourse moves for the experimental class (purple) and comparison class (green)



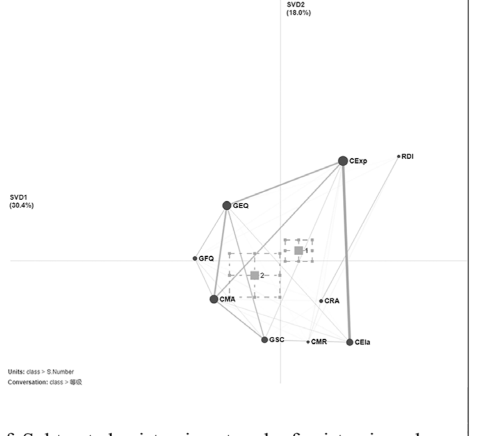
c. Emotional and metacognitive discourse moves for the experimental class (red) and comparison class (blue) represented by points and centroids



d. Subtracted epistemic network of emotional and metacognitive discourse moves for the experimental class (red) and comparison class (blue)



e. Epistemic and metacognitive discourse moves for the experimental class (pink) and comparison class (orange) represented by points and centroids



f. Subtracted epistemic network of epistemic and metacognitive discourse moves for the experimental class (pink) and comparison class (orange) the most significant connections responsible for the differences between the two classes. Compared with the comparison class, the experimental class made more connections to the RDI ("reflecting and deepening inquiry"), JOY, and CUR nodes, suggesting that this class made significant links between higher-level metacognitive discourse moves and academic emotions, and between productive academic emotions. In contrast, compared with the experimental class, the comparison class made a higher number of connections to the CON node, suggesting that this class made significant links between the relatively lower-level metacognitive discourse move CMA and the neutral emotion of confusion, and between neutral emotions and productive emotions of curiosity (CUR). These results indicate that portfolio-supported reflective assessment helped the participants to monitor and regulate their academic emotions, and thus engage in more effective knowledge-building inquiry.

Figure 3e displays a plot of epistemic and metacognitive discourse moves in the experimental and comparison classes, indicating the significant differences between the two classes. Specifically, independent-samples t-tests of the mean centroid values of the two classes showed that there were statistically significant differences between the classes along the x-axis (t [20.87] = 3.30; $p < 0.05$; and d = 1.23) and along the y-axis (t [19.67] = 2.18; $p < 0.05$; and d = 0.83). We also examined the connection differences between the two classes. Figure 3f shows that compared with the comparison class, the students in the experimental class made more connections to the RDI and CExp nodes, suggesting that these students made a significant link between higher-level metacognitive discourse moves and epistemic discourse moves such as RAC, a significant link between higher-level epistemic discourse moves such as CExp and GEQ, and a significant link between higher-level and lower-level epistemic discourse moves such as CExp and CEIa. However, the studentss in the comparison class made more connections to the CMA and GSC ("generating a simple claim") nodes, and these were relatively lower-level metacognitive and epistemic discourse moves. These results suggest that portfolio-supported reflective assessment supported the participants' productive epistemic engagement by encouraging them to contribute more higher-level metacognitive and epistemic discourse moves and to productively monitor and regulate their epistemic engagement.

DISCUSSION AND CONCLUSIONS

Effects of reflective assessment-augmented knowledge-building inquiry on low-achieving students' PDE

Helping students engage in disciplinary learning and develop higher-level skills is an important research strand in the learning sciences, such as research on fostering communities of learners (Brown, 1992; Brown & Campione, 1994, 1996; Lamon et al., 1996) and knowledge building (Chen & Hong, 2016; Scardamalia, 2002; Scardamalia & Bereiter, 2014). The current study builds on this research strand, which emphasizes students' agency, collaborative inquiry, reflection, and authentic and meaningful inquiry. The study involved the design of a knowledge-building inquiry environment and a portfolio-supported reflective assessment process in Knowledge Forum to support low-achieving students' engagement in learning about the visual arts. We examined the effects of this design in facilitating PDE by analysing the low-achieving students' online discourse using a coding framework for the cognitive, emotional, and epistemic aspects of PDE.

FIGURE 3 Means (from epistemic network analysis) and subtracted networks for the experimental class and comparison class. See abbreviations in Table 1.

The frequency distributions of higher-level discourse moves revealed more higher-level engagement in cognitive, emotional and epistemic aspects of PDE occurred in the experimental class than in the comparison class. Further analysis of these three aspects revealed more productive sequential transition patterns of discourse moves occurred in the experimental class than in the comparison class. These results suggest that reflective assessment-augmented knowledge-building inquiry has positive effects on low-achieving students' PDE. This is consistent with our previous research on the facilitation of low-achieving students' knowledge-building through an analytics-supported reflective assessment process (Yang et al., 2016; Yang, 2019; Yang, van Aalst, et al., 2020). These results also extend the literature on the characterization and conceptualization of PDE (Engle & Conant, 2002; Gomoll et al., 2017; Sinha et al., 2015) and the development of guiding principles to support student PDE (Engle, 2012; Engle & Conant, 2002).

The present study focused on designing interventions to support low-achieving students' PDE and to extend PDE from the individual and group dimensions to the community dimension. Our finding illustrates the use of knowledge-building inquiry and reflective assessment to support low-achieving students' PDE in an Asian context that emphasizes an examination culture. In the study, we emphasized the role of Knowledge Forum that helped students focus on disciplinary ideas, discourse and practices and provided functions (eg, reference and rise-above) and tools (eg, embedded assessment tools) for working with and advancing ideas and developing knowledge building inquires and practices.

Reflective assessment mechanisms to support low-achieving students' PDE

Understanding the mechanisms through which reflective assessment helps low-achieving students to engage in disciplinary learning is critical for providing appropriate support to scaffold low-achieving students' PDE in a given discipline. Our previous studies have mainly relied on qualitative analysis of low-achieving students' reflections documented in their worksheets to guide their productive reflection through reflective assessment (Yang, 2019; Yang et al., 2016; Yang, van Aalst, et al., 2020). These findings can help us understand the process by which reflective assessment helps low-achieving students to engage in productive analysis of their knowledge building, reflect on their strengths and weaknesses, and plan actions to deepen their inquiries. However, these findings cannot reveal the connections between metacognitive processes and cognitive, emotional and epistemic processes. Thus, the current study examined these connections using epistemic network analysis to reveal how reflective assessment helps low-achieving students to develop PDE.

The results of this study show that with the help of reflective assessment, low-achieving students were more likely to collectively reflect on, monitor and regulate their collective inquiry, as indicated by their greater percentage of metacognitive discourse moves than low-achieving students who did not engage in reflective assessment. These behaviours of low-achieving students who engaged in reflective assessment increased their engagement in higher-level cognition and emotion during knowledge-building inquiries. These results support the argument of Bereiter et al. (2019) that metacognitive engagement strengthens students' epistemic agency, and the results of Chan et al., (2019) that show students with deeper meta-knowledge are more likely to engage in productive knowledge-building inquiries and discussion than those without such knowledge.

The knowledge-building inquiry model emphasizes the scaffolding and transformative function of reflective assessment and student agency in gradually pursuing inquiry, co-directing inquiry and building knowledge. The reflective assessment-augmented knowledge-building inquiry design of the current study made this explicit in the knowledge-building process.

Engaging low-achieving students in portfolio-supported reflective assessment involved them in several rounds of metacognitive processes comprising gap analysis, reflection, and action planning. Through these processes, low-achieving students gradually internalized the necessary metacognitive cycles. This design thus has important implications for practitioners and researchers who aim to design technology-rich collaborative and reflective inquiry environments to support student inquiry, engagement, agency, and learning. Additionally, this study highlighted the instructors' key role in facilitating low-achieving students' knowledge-building inquiry. Moreover, the study highlighted the instructors' strong belief that low-achieving students can engage in knowledge-building inquiry if they are provided with appropriate scaffolding, and that knowledge-building inquiry can benefit low-achieving students by valuing their inquiry, collaboration, agency and reflection.

Implications for educational practices to help low-achieving students' development of higher-order skills and PDE

The study has several implications for designing technology-enhanced collaborative inquiry and reflective inquiry to support low-achieving students' development of higher-level skills and PDE. First, it is crucial to create a collaborative and reflective community culture with a set of agency-oriented activities to help low-achieving students gradually gain agency by conducting knowledge-building inquiries and co-designing and co-directing these inquiries. The culture and set of activities should (1) empower low-achieving students to actively pursue inquiries collaboratively, reflect on and regulate their inquiry and knowledge building, and build disciplinary knowledge and theories; (2) encourage low-achieving students to participate democratically in community idea building; and (3) help low-achieving students to develop a strong belief that their contribution is important to the whole community and that every idea can be gradually improved through collaborative effort. Second, it is critical to help low-achieving students to develop a productive belief that idea improvement and reflection is a continuous and iterative process. Third, although reflective assessment can help low-achieving students to develop PDE, this benefit requires face-to-face knowledge-building discussion and collaborative reflection opportunities that encourage low-achieving students to engage in meta-level discussion. Integrating face-to-face group-level reflection with online Knowledge Forum inquiry contributes to successful reflective assessment.

Limitation and implications for future research

This study has several limitations that provide promising research opportunities. First, we did not investigate the changes in students' disciplinary understanding. Our findings revealed that reflective assessment-augmented knowledge-building inquiry has positive effects on low-achieving students' PDE, however it remains unclear whether this change is transferable. As transfer is a key issue in the learning sciences (Lobato, 2008), it is important to determine the transferability of the effects we observed.

Second, we used only low-achieving students' online discourse to examine the effects of reflective assessment-augmented knowledge-building inquiry and how reflective assessment supports low-achieving students' PDE. However, classroom data sources such as interviews and video recordings are also important for delineating the mechanism of reflective assessment. Fortunately, the use of epistemic network analysis was adequate for modelling various epistemic networks and revealing the mechanism by which reflective assessment affects low-achieving students' PDE. However, we aim to conduct future qualitative analysis to produce a rich set of classroom data sources from a broader range of schools and teachers, which will allow us to more deeply examine the dynamics of reflective assessment.

Third, as demonstrated in this study, Chinese learners are not inherently passive rote-learners as described in the literature (Yin et al., 2014), but respond appropriately to a contextual background and various design elements and learning demands. Nonetheless, we did not explore how design is implemented in Chinese classrooms to relieve the tensions between cultural beliefs, contextual demands and Western ideas (Chan, 2010). Future research is needed to address this limitation.

ACKNOWLEDGMENTS

Yuqin Yang acknowledges the financial support from the National Natural Science Foundation of China (Grant No. 62107020), Ministry of Education of the People's Republic of China (Grant No. 21YJA880078), and Central China Normal University, China (CCNUTEIII 2021-11).

CONFLICT OF INTEREST

This research has no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

ETHICS STATEMENT

The data of this study cannot be made openly available due to confidentiality agreements and ethical concerns. The data samples and detailed coding procedures can be accessed by contacting the author. Ethical approvals were gained from the hosting institution.

ORCID

Yuqin Yang https://orcid.org/0000-0001-7125-3716

REFERENCES

Azevedo, R., Cromley, J. G., & Seibert, D. (2004). Does adaptive scaffolding facilitate students' ability to regulate their learning with hypermedia? *Contemporary Educational Psychology*, *29*, 344–370.

Bakeman, R., & Gottman, J. M. (1997). *Observing interaction. An introduction to sequential analysis*. Cambridge University Press.

Bakeman, R., & Quera, V. (2011). *Sequential analysis and observational methods for the behavioral sciences*. Cambridge University Press.

Barron, B. (2003). When smart groups fail. *The Journal of the Learning Sciences*, *12*, 307–359.

Baxter, J. A., Woodward, J., & Deborah, O. (2001). Effects of reform-based mathematics instruction on low achievers in five third-grade classrooms. *The Elementary School Journal*, *101*, 529–547.

Becker, B. E., & Luthar, S. S. (2002). Social-emotional factors affecting achievement outcomes among disadvantaged students: Closing the achievement gap. *Educational Psychologist*, *37*(4), 197–214.

Bereiter, C., Chan, C. K. K., Hong, H.-Y., Lee, J., Khanlari, A., Lin, P. Y., Chai, C. S., Tsai, C. C., Scardamalia, M., Tan, S. C., Tong, Y., van Aalst, J., Zhang, J., & Zhang, Y. (2019). The roles of knowledge in knowledge creation. In K. Lund, G. P. Niccolai, E. Lavoué, C. Hmelo-Silver, G. Gweon, & M. Baker (Eds.), *A wide lens: Combining embodied, enactive, extended, and embedded learning in collaborative settings, 13th International Conference on Computer Supported Collaborative Learning (CSCL) 2019* (Vol. 2, pp. 767–774). International Society of the Learning Sciences. https://bit.ly/3codUXo

Bereiter, C., Scardamalia, M., Cassells, C., & Hewitt, J. (1997). Postmodernism, knowledge building, and elementary science. *The Elementary School Journal*, *97*(4), 329–340.

Bransford, J. D., Brown, A. L., & Cocking, R. R. (1999). *How people learn: Brain, mind, experience, and school*. National Academy Press.

Brown, A. (1997). Transforming schools into communities of thinking and learning about serious matters. *American Psychologist*, *52*, 399–413.

Brown, A. L. (1992). Design experiments: Theoretical and methodological challenges in creating com- plex interventions in classroom settings. *Journal of the Learning Sciences*, *2*(2), 141–178.

Brown, A. L., & Campione, J. C. (1994). Guided discovery in a community of learners. In K. McGilly (Ed.), *Classroom lessons: Integrating cognitive theory and classroom practice* (pp. 229–270). MIT Press.

Brown, A. L., & Campione, J. C. (1996). Psychological theory and the design of innovative learning environments: On procedures, principles, and systems. In L. Schauble & R. Glaser (Eds.), *Innovations in learning: New environments for education* (pp. 289–325). Lawrence Erlbaum Associates, Inc.

Calabrese Barton, A., & Tan, E. (2010). We be burnin'! Agency, identity, and science learning. *Journal of the Learning Sciences*, *19*(2), 187–229.

Chan, C. K. K. (2010). Classroom innovation for the Chinese learner: Transcending dichotomies and transforming pedagogy. In C. K. K. Chan & N. Rao (Eds.), *Revisiting the Chinese learner* (pp. 169–210). Springer.

Chan, C. K. K. (2011). Bridging research and practice: Implementing and sustaining knowledge building in Hong Kong classrooms. *International Journal of Computer-Supported Collaborative Learning*, *6*, 147–186.

Chan, C. K. K., Tong, Y., & van Aalst, J. (2019). Progressive dialogue in computer-supported collaborative knowledge Building. In N. Mercer, R. Wegerif, & L. Major (Eds.), *The Routledge International Handbook of Research on Dialogic Education* (pp. 776–799). Routledge.

Chen, B. (2017). Fostering scientific understanding and epistemic beliefs through judgments of promisingness. *Educational Technology Research & Development*, *65*, 255–277.

Chen, B., & Hong, H.-Y. (2016). Schools as knowledge-building organizations: Thirty years of design research. *Educational Psychologist*, *51*, 266–288.

Dietrichson, J., Bøg, M., Filges, T., & Jørgensen, A. (2017). Academic interventions for elementary and middle school students with low socioeconomic status: A systematic review and meta-analysis. *Review of Educational Research*, *87*, 243–282.

D'Mello, S. K., & Graesser, A. C. (2012). Dynamics of affective states during complex learning. *Learning and Instruction*, *22*, 145–157. https://doi.org/10.1016/j.learninstruc.2011.10.001

Engle, R. A. (2012). The productive disciplinary engagement framework: Origins, key concepts and developments. In D. Y. Dai (Ed.), *Design research on learning and thinking in educational settings: Enhancing intellectual growth and functioning* (pp. 161–200). Routledge.

Engle, R. A., & Conant, F. C. (2002). Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners' classroom. *Cognition and Instruction*, *20*(4), 399–483.

Fredricks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School engagement: Potential of the concept, state of the evidence. *Review of Educational Research*, *74*(1), 59–109.

Gomoll, A. S., Hmelo-Silver, C. E., Tolar, E., Šabanović, S., & Francisco, M. (2017). Moving apart and coming together: Discourse, engagement, and deep learning. *Educational Technology & Society*, *20*(4), 219–232.

Han, S., Capraro, R., & Capraro, M. M. (2015). How science, technology, engineering, and mathematics (STEM) project-based learning (PBL) affects high, middle, and low achievers differently: The impact of student factors on achievement. *International Journal of Science and Mathematics Education*, *13*, 1089–1113.

Järvelä, S., Kirschner, P. A., Panadero, E., Malmberg, J., Phielix, C., Jaspers, J., Koivuniemi, M., & Järvenoja, H. (2015). Enhancing socially shared regulation in collaborative learning groups: Designing for CSCL regulation tools. *Educational Technology Research and Development*, *63*, 125–142.

Jordan, M. E., Zuiker, S., Wakefield, W., & DeLaRosa, M. (2021). Real work with real consequences: Enlisting community energy engineering as an approach to envisioning engineering in context. *Journal of Pre-College Engineering Education Research*, *11*(1), 13.

Lamon, M., Secules, T., Petrosino, A. J., Hackett, R., Bransford, J. D., & Goldman, S. R. (1996). Schools for thought: Overview of the project and lessons learned from one of the sites. In L. Schauble & R. Glaser (Eds.), *Innovations in learning: New environments for education* (pp. 243–288). Lawrence Erlbaum Associates, Inc.

Lee, E. Y., Chan, C. K., & van Aalst, J. (2006). Students assessing their own collaborative knowledge building. *International Journal of Computer-Supported Collaborative Learning*, *1*, 277–307.

Lei, C., & Chan, C. K. K. (2018). Developing metadiscourse through reflective assessment in knowledge building environments. *Computers & Education*, *126*, 153–169.

Lobato, J. (2008). Research methods for alternative approaches to transfer: Implications for design experiments. In A. E. Kelly, R. A. Lesh, & J. Y. Baek (Eds.), *Handbook of design research methods in education: Innovations in science, technology, engineering, and mathematics learning and teaching* (pp. 167–194). Routledge.

Pekrun, R., Vogl, E., Muis, K. R., & Sinatra, G. M. (2017). Measuring emotions during epistemic activities: The epistemically-related emotion scales. *Cognition and Emotion*, *31*(6), 1268–1276. https://doi.org/10.1111/cdev.12704

Raes, A., Schellens, T., & De Wever, B. (2014). Web-based collaborative inquiry to bridge gaps in secondary science education. *Journal of the Learning Sciences*, *23*, 316–347.

Scardamalia, M. (2002). Collective cognitive responsibility for the advancement of knowledge. In B. Smith (Ed.), *Liberal education in a knowledge society* (pp. 67–98). Open Court.

Scardamalia, M., & Bereiter, C. (2006). Knowledge building: Theory, pedagogy, and technology. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (pp. 97–116). Cambridge University Press.
Scardamalia, M., & Bereiter, C. (2014). Knowledge building and knowledge creation: Theory, pedagogy, and technology. In R. K. Sawyer (Ed.), *The Cambridge handbook of the learning sciences* (2nd ed., pp. 397–417). Cambridge University Press.
Shaffer, D. W. (2017). *Quantitative ethnography*. Cathcart Press.
Shen, P. D., Lee, T. H., & Tsai, C. W. (2007). Applying Web-enabled problem-based learning and self-regulated learning to enhance computing skills of Taiwan's vocational students: A quasi-experimental study of a short-term module. *Electronic Journal of e-Learning*, *5*(2), 147–156.
Sinha, S., Rogat, T. K., Adams-Wiggins, K. R., & Hmelo-Silver, C. E. (2015). Collaborative group engagement in a computer-supported inquiry learning environment. *International Journal of Computer Supported Collaborative Learning*, *10*(3), 273–307.
Snell, J., & Lefstein, A. (2018). "Low ability," participation, and identity in dialogic pedagogy. *American Educational Research Journal*, *55*, 40–78.
Stahl, G. (2006). *Group cognition: Computer support for building collaborative knowledge*. MIT Press.
Tao, D., & Zhang, J. (2021). Agency to transform: How did a grade 5 community co-configure dynamic knowledge building practices in a yearlong science inquiry? *International Journal of Computer-Supported Collaborative Learning*, *16*, 1–32.
Van Aalst, J. (2009). Distinguishing knowledge sharing, construction, and creation discourses. *International Journal of Computer-Supported Collaborative Learning*, *4*, 259–288.
Van Aalst, J., & Chan, C. K. K. (2007). Student-directed assessment of knowledge building using electronic portfolios. *The Journal of the Learning Sciences*, *16*, 175–220.
White, B., & Frederiksen, J. (1998). Inquiry, modeling, and metacognition: Making science accessible to all students. *Cognition and Instruction*, *16*, 3–118.
White, B., & Frederiksen, J. (2005). A theoretical framework and approach for fostering metacognitive development. *Educational Psychologist*, *40*(4), 211–223.
Yang, Y. (2019). Reflective assessment for epistemic agency of academically low-achieving students. *Journal of Computer Assisted Learning*, *35*, 459–475.
Yang, Y., Chen, Q., Yu, Y., Feng, X., & van Aalst, J. (2020). Collective reflective assessment for shared epistemic agency by undergraduates in knowledge building. *British Journal of Educational Technology*, *51*, 1136–1154.
Yang, Y., van Aalst, J., & Chan, C. K. K. (2020). Dynamics of reflective assessment and knowledge building for academically low-achieving students. *American Educational Research Journal*, *57*(3), 1241–1289.
Yang, Y., van Aalst, J., Chan, C. K. K., & Tian, W. (2016). Reflective assessment in knowledge building by students with low academic achievement. *International Journal of Computer-Supported Collaborative Learning*, *11*, 281–311.
Yang, Y., Zhu, G., Sun, D., & Chan, C. K. K. (2022). Collaborative analytics-supported reflective assessment for scaffolding pre-service teachers' collaborative inquiry and knowledge building. *International Journal of Computer-Supported Collaborative Learning*, *17*, 249–292.
Yin, H., Lee, J. C.-K., & Wang, W. (2014). Dilemmas of leading national curriculum reform in a global era: A Chinese perspective. *Educational Management Administration & Leadership*, *42*(2), 293–311.
Zhang, J., Scardamalia, M., Lamon, M., Messina, R., & Reeve, R. (2007). Socio-cognitive dynamics of knowledge building in the work of 9-and 10-year-olds. *Educational Technology Research and Development*, *55*, 117–145.
Zhang, J., Tao, D., Chen, M. H., Sun, Y., Judson, D., & Naqvi, S. (2018). Co-organizing the collective journey of inquiry with idea thread mapper. *Journal of the Learning Sciences*, *27*, 390–430.
Zohar, A., & Dori, Y. J. (2003). Higher order thinking skills and low-achieving students: Are they mutually exclusive? *Journal of the Learning Sciences*, *12*, 145–181.

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Yang, Y., Yuan, K., Feng, X., Li, X.,& van Aalst, J. (2022). Fostering low-achieving students' productive disciplinary engagement through knowledge-building inquiry and reflective assessment. *British Journal of Educational Technology*, *00*, 1–19. https://doi.org/10.1111/bjet.13267