Collective reflective assessment for shared epistemic agency by undergraduates in knowledge building

Yuqin Yang, Qianqian Chen, Yawen Yu, Xueqi Feng and Jan van Aalst

Introduction
Empowering students to master future-ready high-level competences should help them create a foundation for improving their academic performance, as well as life-long learning and continuous development (Becker & Luthar, 2002; Snell & Lefstein, 2018). Collaborative inquiry, nowadays a major research strand in education, can help students to develop these future-ready competences, such as inquiry, collaboration, knowledge creation, agency and metacognition. However, the development of these competences relies heavily on students’ enactment of...

Abstract
We examined the facilitation of shared epistemic agency through a knowledge-building (KB) design that included analytics-supported collective reflective assessment (AsCRA). Forty undergraduate students taking a Liberal Studies course at a university in central China used the promising ideas tool and the knowledge building discourse explorer to self-analyze the online discourse they had created in Knowledge Forum® (KF), an online discourse environment; 34 students in a comparison section of the same course used KF but did not use the additional tools. Both classes were taught by the same teacher and studied the same inquiry topics. Multifaceted analysis of students’ interaction in and the quality of discourse on KF, an educational online platform, indicated that analytics-supported reflective assessment helped them to develop high-level shared epistemic agency in the KB process. Qualitative analysis showed that AsCRA helped students to focus on high-level goals (idea negotiation, synthesis of ideas and rise above thinking) in KB, and to engage in continuous assessment, reflection, and action planning to regulate and improve their discourse. The findings have important implications for the design of technology-rich environments to support learners, and may help teachers identify the potential uses of such environments to encourage learners to engage in productive collaborative inquiry and develop metacognition and agency.

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high-level shared epistemic agency (Damşa, 2014; Oshima, Oshima, & Fujita, 2018; Rappa & Tang, 2017; Scardamalia & Bereiter, 2014; Zhang et al., 2018). This is problematic because many students exhibit little shared epistemic agency in collaborative inquiry. Therefore, students need appropriate support to develop high levels of shared epistemic agency to benefit from collaborative inquiry. Here, “shared epistemic agency” refers to a “capacity that enables groups to deliberately carry out collaborative, knowledge-driven activities with the aim of creating shared knowledge objects” (Damşa, Kirschner, Andriessen, Erkens, & Sins, 2010, p. 154). This definition emphasizes the fundamental collective responsibility and contribution of the students, and goes beyond individual agency.

Reflective assessment—a type of assessment that drives students to actualize a set of critical metacognitive skills for achieving high-level epistemic agency (Scardamalia, 2002; van Aalst & Chan, 2007; Yang, van Aalst, & Chan, 2019)—has been shown to be effective in scaffolding students’ collaborative inquiry and epistemic agency. However, little research exists that has investigated ways to promote high levels of shared epistemic agency in knowledge building (KB), an influential model in the field of the learning sciences. For clarity we capitalize the term “AsCRA” to refer to this scaffolding strategy.

**Conceptual framework**

*Shared epistemic agency*

High levels of shared epistemic agency are critical for productive collaborative inquiry; without this, collaborative inquiry may have limited benefits for students (Yang, 2019). Epistemic agency
Reflective assessment for shared epistemic agency

is one of the core principles of KB. It is defined as students’ intentional engagement in collective knowledge advancement (Scardamalia, 2002), and characterized by the improvement of ideas through collaborative effort and collective contributions (Scardamalia & Bereiter, 2014). Damşa et al. (2010) extended this principle to comprise both individual and collective intentionality for collaborative activities, and to focus more on the collective level of agency during collaborative activities.

Damşa et al. (2010) proposed that shared epistemic agency included both epistemic and metacognitive dimensions. The epistemic dimension requires students to work with ideas intentionally, collaboratively, and in a sustained manner during knowledge-driven collaborative activities such as identifying knowledge gaps, creating collective common understanding, negotiating between different ideas, synthesizing diverse ideas, and generating new ideas (Borge, Ong, & Rosé, 2018; Damşa, 2014; Damşa et al., 2010; Yang, 2019). The metacognitive dimension requires students to participate in a series of metacognitive activities, including planning future activities and creating a joint plan, monitoring progress towards goals, coordinating objective-related activities, and reflecting on and regulating their collaborative activities (Damşa, 2014; Damşa et al., 2010; Scardamalia, 2002; Yang, 2019). Such metacognitive activities are necessary to support and direct sustained knowledge-related collaborative inquiry (Damşa, 2014; Damşa et al., 2010; Yang, 2019; Yang et al., 2019; Yang et al., 2016).

Previous research has revealed the significance of shared epistemic agency in knowledge-related collaborative inquiry (e.g., Lei & Chan, 2018; Oshima et al., 2018; Yang, 2019), and some studies have demonstrated the positive effects of high-level shared epistemic agency on domain understanding (Yang, 2019; Yang et al., 2019; Zhang et al., 2018), the productivity of collaboration (Damşa, 2014), collective knowledge advancements (Oshima et al., 2018; Yang, 2019), and the development of high-level competences among students (Borge et al., 2018; Chen, 2017; Yang, 2019). Shared epistemic agency is essential for sustaining collaborative efforts to pursue knowledge advancement (Damşa et al., 2010; Scardamalia, 2002). However, very few practical studies have examined shared epistemic agency supported through learning design and scaffolding. Simply bringing students together in collaborative activities is not sufficient for them to develop shared epistemic agency; appropriate scaffolds are needed to support students’ deployment and development of high levels of shared epistemic agency.

Fostering shared epistemic agency through knowledge-building design augmented by AsCRA

KB community model

The phrase “Knowledge building” (KB) refers to the process by which students take on shared epistemic agency to advance the community’s state of knowledge (Scardamalia, 2002). KB is a principle-based educational approach consisting of 12 interconnected principles (Scardamalia, 2002). The principles of epistemic agency, community knowledge, improvable ideas, and reflective and transformative assessment are particularly important to students’ collective epistemic agency (Yang, 2019; Yang et al., 2019). KB, designed under the guidance of the KB principles, has been implemented across a broad range of subjects in classrooms internationally. Research on KB has shown substantial progress in developing learning designs and scaffolds for sustained KB in the last 30 years (for a review, see Chen & Hong, 2016).

Epistemic agency is one of the 12 principles that guides the works of KB communities and practices in real classrooms (Scardamalia, 2002; Scardamalia & Bereiter, 2006, 2014). Epistemic agency in KB manifests a “sharedness” dimension. Shared epistemic agency is essential to support the sustained collaborative efforts of knowledge advancement (Damşa et al., 2010; Scardamalia, 2002). Empirical research on KB has rarely focused on fostering students’ shared epistemic
agency, although the literature has pointed to several characteristics of the KB process related to epistemic agency and has occasionally discussed epistemic agency in relation to metacognition, inquiry and knowledge advances (Lee, Chan, & van Aalst, 2006; van Aalst & Chan, 2007).

KB involves more than problem solving and ideation in discourse. Specific inquiries should be understood in the context of the community’s other inquiries (past and current) and its effort to build a “big-picture” understanding of a domain (Van Aalst, 2009). Therefore, appropriate learning designs and scaffolding tools and methods should be provided to help students participate in shared epistemic agency to collectively engage in ongoing review and reflection on collective advances and gaps, and regularly synthesize and transcend ideas in KB.

Collective reflective assessment augmented by analytic tools

“Collective reflective assessment” refers to students’ assuming collective agency to set learning goals, monitor personal and community progress, use feedback to identify knowledge gaps and examine how to improve their ongoing learning to address broader problems (Scardamalia, 2002; Yang, 2019; Yang et al., 2016). Collective reflective assessment that incorporates the metacognitive components of planning, monitoring and reflecting drives students to collectively deploy and develop their metacognitive skills and directs them to improve their ongoing learning. Involvement in these metacognitive processes is critical to the development of collective epistemic agency.

Prior research on KB and reflective assessment has indicated benefits for participating students (Lee et al., 2006; Lei & Chan, 2018; van Aalst & Chan, 2007). For example, previous research (Lee et al., 2006; Lei & Chan, 2018; van Aalst & Chan, 2007) on the use of electronic portfolios (one type of student-directed reflective assessment) on KB, in which students are given agency to self-assess and reflect on their performance in KB, revealed the scaffolding function of this type of assessment. Through this task, students improved their understanding of the nature of KB and recognized how they could put their efforts into discourse on KB (van Aalst & Chan, 2007).

Studies (Yang, 2019; Yang et al., 2016, 2019) have also been conducted on AsCRA in KB, in which students reflectively assessed their online discussion data using an analytic tool. The students involved, including those with low academic attainment, progressively improved their KB and developed a deep domain understanding. In the current study, we provided students with data from agency-supported analytic tools to encourage them to engage in productive collective reflective assessment in the KB process, and thus help them to develop collective epistemic agency.

The present study

We designed collective reflective assessment using two analytic tools—the Promising Ideas Tool (PIT; Chen, 2017) and the knowledge building discourse explorer (KBDeX; Oshima, Oshima, & Matsuzawa, 2012)—in a KB community to help students develop shared epistemic agency. The study was part of a larger project investigating the design, impacts, process and dynamics of AsCRA for students’ high-level competences during KB. We propose that the framework of the KB model enhanced by analytics-supported collaborative reflective assessment can help undergraduates to develop high levels of shared epistemic agency. The study aimed to examine the impact and process of AsCRA for promoting high-level shared epistemic agency among undergraduates in a KB design. The following research questions were investigated:

1. Do undergraduates in the KB design augmented by AsCRA improve more in collective knowledge advancement than undergraduates in a KB environment using portfolio assessment?
2. To what extent is shared epistemic agency of undergraduates improved by AsCRA?
3. In what ways does AsCRA help undergraduates to engage in high-level shared epistemic agency?
Reflective assessment for shared epistemic agency

The PIT (Chen, 2017) was originally designed as a separate learning-analytic tool but is now embedded in KF. It can help students to select promising ideas among their community’s ideas, and supports collective decision making to identify promising directions for further inquiry (Chen, 2017). The KBDeX is a learning-analytic tool designed to investigate student-, keyword- and discourse-based networks on KF (Oshima et al., 2012). However, most current studies have used the KBDeX only as a tool for evaluating learning processes (eg, Ma, Matsuzawa, Chen, & Scardamalia, 2016). This study aims to design the use of PIT and representations of KBDeX, and to examine the designed environment’s impact on undergraduates’ high-level shared epistemic agency.

Method

Participants and context
The study used a quasi-experimental design with two intact undergraduate classes; it was conducted at a teacher training institution in central China. The study sample consisted of one class of 40 undergraduates in a KB environment augmented by reflective assessment using PIT and KBDeX. The comparison class (n = 33) engaged in a regular KB environment without AsCRA. Both classes included undergraduates from 24 disciplines across the university and reported similar levels of pre-intervention domain understanding in a pretest; no significant differences in students’ domain understanding were found between the experimental class (M = 1.98, SD = 0.58) and the comparison class (M = 2.00, SD = 0.50), t(71) = −.20, p > .01 (for details of analyzing domain understanding, see Yang, 2019). The two classes also had similar compositions in terms of sex: the experimental class was 62.50% female and 37.50% male, and the comparison class was 63.64% female and 36.36% male. Both classes studied the same topics regarding scientific inquiry and knowledge creation alongside a core course of liberal education over 4 months with two lessons (1.5 hours total) per week. The aims of the course were to help undergraduates deploy and develop high-level skills in the process of inquiry and creating knowledge. In the initial stage, most of the students exhibited low levels of motivation and agency and limited collaboration skills. They had enrolled in this course to meet an obligatory credit requirements for graduation. The course teacher (the first author) had 2 years of teaching experience and had a doctoral degree in the learning sciences.

Design of the KB environment augmented by AsCRA (Intervention)

The pedagogy used in the KB experimental class focused on reflective and transformative assessment, epistemic agency and community knowledge. The teacher used a three-component model adopted from earlier studies by Van Aalst and Chan (2012), Yang (2019), and Yang et al. (2019) to encourage undergraduates to gradually assume high-level shared epistemic agency in the KB process.

Developing a collaborative metacognitive culture for shared epistemic agency (Component 1, Weeks 1–6)

The activities to gradually develop the collaborative and metacognitive skills needed for shared epistemic agency. For example, small groups (6–7 students) were required to design a poster on how to stay motivated and persistent in learning and scientific inquiry. They were encouraged to take part in small-group and whole-class discussions and activities in the process. They were also encouraged to sign a learning contract that consisted of an agenda for the course. This helped the students to monitor their own learning and directed them to complete their tasks.

Initiating problem-centered inquiry and fostering shared epistemic agency on KF (Component 2, Weeks 3–9)

Initially, the students were guided to work together to pursue inquiries on how to develop competencies required for scientific inquiry and knowledge creation using KF (Figure 1). The teacher
created collective reflections on what constituted good notes and good KB discussions using examples from previous KB classes. The teacher also created reflection opportunities using KF’s integrated assessment tools (eg, applets measuring the number of notes created and read) to help students reflect on their KB discussion and contribution and develop epistemic agency.

Fostering higher level shared epistemic agency through AsCRA (Component 3, Weeks 10–18)

As the KB discourse progressed, the students contributed a variety of inquiry questions and ideas. However, many discussion threads (Figure 1) were superficial, without seeking to improve on ideas. The teacher thus introduced the analytic tools (PIT and KBDeX) to help students engage in reflective assessment. The teacher first introduced the students to the PIT (Figure 1) to help students identify promising ideas, facilitate a discussion about them and elevate students’ inquiry to a higher conceptual level (referred to in KB as “rise-above thinking”). The detailed process of using the PIT for conducting reflective assessment was presented in Figure 2.

Instruction in the comparison class

The students in the comparison class inquired into the same topics and participated in collaborative inquiry in the KB model with facilitation from the same teacher as the experimental class.
During Components 1 and 2, both classes carried out the same tasks; their work only began to differ in the third phase. In Component 3, the comparison class was encouraged to enact high-level epistemic agency by creating portfolio notes individually and collectively using KB principles (Lee et al., 2006; van Aalst & Chan, 2007). As mentioned earlier, the experimental class was scaffolded to develop high-level shared epistemic agency through engaging collective reflective assessment using the PIT and KBDeX.

**Measures and analysis**

**KF discourse**

The notes posted by the undergraduates on KF served as the primary data source for understanding the development of their shared epistemic agency. We argue that students’ shared epistemic
agency is reflected in their ability to collectively advance the community’s KB discourse; if they gradually assume higher level shared epistemic agency, they can contribute to KF discourse with both epistemic and regulative actions as reflected by their conceptualization, collaboration, synthesis and sustained pursuit of inquiry.

We first conducted inquiry thread analysis to pre-process the KF discourse into different inquiry threads that were used as a unit of analysis for the subsequent content analysis. An inquiry thread is “a series of notes that address a shared principal problem and constitute a conceptual stream in a community knowledge space” (Zhang, Scardamalia, Lamon, Messina, & Reeve, 2007). Inquiry thread analysis is a validated and commonly method for analyzing online discourse in KB research (eg, Yang, 2019; Yang et al., 2016; Zhang et al., 2007); it is a method of reconstructing original discussion threads to obtain a holistic understanding of the students’ notes (Zhang et al., 2007, p. 125). In conducting inquiry thread analysis, we first identified the principal problems by reading and re-reading all of the notes on KF, followed by clustering notes that addressed the same problem into one inquiry thread. Regarding the detailed process of inquiry thread analysis, see Zhang et al. (2007) and Yang (2019). The experimental class created 1129 notes, and the comparison class 696 notes; these were categorized into inquiry threads. Twenty-six inquiry threads from each class were identified for analysis. Most of the inquiry threads continued more than 10 weeks (22 in the experimental class and 17 in the comparison class) suggesting that students sustained their interest in the corresponding topics. An independent researcher individually identified inquiry threads of 420 notes (>30%) from two inquiry topics in the experimental class, with an inter-coder reliability of 0.83 (Cohen’s kappa).

Next, we used the coding framework of Yang (2019) to conduct content analysis of the notes in the inquiry threads to examine the students’ shared epistemic agency. The coding framework comprised epistemic and regulative dimensions, with the epistemic dimension consisting of categories of questions, ideas and collaborative KB (for details see Yang, 2019). Two raters independently
coded the notes from eight inquiry threads generated from the above inquiry thread analysis of 420 notes in two inquiry topics, resulting in an inter-rater consistency of 100% for questions, 98% for ideas, 92% for community and 96% for metacognition.

Reflective prompt sheets for developing shared epistemic agency

To illustrate the developmental process of shared epistemic agency through AsCRA, we primarily collected the students’ reflective prompt sheets that were designed for collective reflective assessment. This approach was complemented through focus group interviews, classroom observations and a combination of qualitative and quantitative analyses of data. The prompt sheets were used to record the students’ interpretations of and reflections on the data, and their action planning. They were distributed to the student groups to scaffold their collective reflection in class and were collected after class.

To analyze and identify key events of AsCRA conducive to the students’ enactments of high-level shared epistemic agency, we identified productive and unproductive uses of data from analytics; selected a limited number of events based on KB goals such as synthesis/rise above and idea improvement; and analyzed the potential of reflective assessment to increase students’ focus on the key KB goals.
Results
Changes of collective knowledge advancement
The state of collective knowledge was assumed to be represented by a network of ideas that students created. Thus, collective knowledge advancement can be assessed by the increasing number of meaningful links between ideas. As the degree of a note in the network refers to the number of links attached to it, the cumulative degree centrality in a network represents how dense a network can be (Oshima et al., 2012). Based on this assumption, we used the cumulative degree centrality of discourse network from the KBDeX to assess collective knowledge advancement (Oshima et al., 2012). We compared the increase in the cumulative value of degree centrality of both classes to assess that advancement (Oshima, Ohsaki, Yamada, & Oshima, 2017). A higher degree centrality reveals a denser social network. Figure 5 shows the increasing cumulative degree centrality of discourse network over time indicating how students collectively worked on their KF notes. Both classes showed improvement, but the experimental class showed a faster change in phase 3 when the reflective assessment tools were introduced. In Phases 1 and 2, one-way ANOVAs showed no significant difference of the collective knowledge advancement between the two classes in Phase 1, $F(1, 8) = 2.06, p > .1, \eta^2 = 0.20$ or Phase 2, $F(1, 6) = 1.01, p > .1, \eta^2 = 0.14$. In Phase 3, a significant difference was observed when the experimental class was implemented by the reflective assessment intervention, $F(1, 12) = 24.56, p < .001, \eta^2 = 0.67$. These results indicated that students in the experimental class promoted higher level collective knowledge advancement with the support of reflective assessment tools.

Effects of AsCRA on students’ shared epistemic agency
To investigate the role of AsCRA, we first qualitatively analyzed the characteristics of the shared epistemic agency of the students in both the experimental and comparison classes through content analysis of the online discourse (see Table S2 in Supplementary File). Next, we compared the characteristics of the shared epistemic agency of the two classes, and across the three stages of the experimental and comparison classes, to reveal the development of the students’ shared epistemic agency. This was achieved based on the qualitative tracing of shared epistemic agency within the inquiry threads.
Class differences in shared epistemic agency
As the overarching goal of the study was to examine the effectiveness of AsCRA in supporting students’ shared epistemic agency, we paralleled the epistemic practices of the students from the experimental class with those of their counterparts from the comparison class to conduct a comparative analysis. We focused on analysis of higher level discourse moves, such as “explanatory questions” (Questioning) and “explanations” and “rise-above” (Ideation) in questions and ideas. The results of the detailed coding of the notes within the inquiry threads of the two classes are aggregated here to facilitate comparison, as shown in Table 1.

Table 1 shows that the frequency distributions were significantly different for the two classes. Primarily, the experimental class students generated many more explanatory claims and rise above notes than the comparison class students. Such differences echo a pattern observed from the differences between the two groups for Community, including negotiating a fit, taking up ideas and, in particular, synthesizing across notes. The students in the experimental group engaged in more regulative practices than their peers from the comparison class. The experimental group made significantly more effort to create metacognitive awareness, particularly through major reviews, and to regulate and advance community ideas. These results suggested that analytics-supported reflective assessment fostered more higher level shared epistemic agency in the experimental class students than the comparison group.

Changes in shared epistemic agency over time
To further investigate the impact of AsCRA on the undergraduates’ development of shared epistemic agency, we compared the characteristics of the students’ shared epistemic agency across the three phases in both the experimental and comparison classes (see Table S3 in Supplementary File). We first sequenced the students’ notes according to when each note was created, and then divided the notes in each inquiry thread into three stages (Stages 1, 2 and 3) with equivalent proportions of notes. Next, we calculated and compared the proportion of notes with high-level

<table>
<thead>
<tr>
<th>Table 1: Class differences in high-level shared epistemic agency: frequency and percentage of different categories in epistemic and regulative dimensions</th>
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</thead>
<tbody>
<tr>
<td><strong>Epistemic</strong></td>
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<td><strong>f</strong></td>
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<tr>
<td>Questioning</td>
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<tr>
<td>Explanation-seeking</td>
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<tr>
<td>Ideation</td>
</tr>
<tr>
<td>Explanations</td>
</tr>
<tr>
<td>Rise above</td>
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<tr>
<td>Community</td>
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<tr>
<td>Negotiating a fit</td>
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<tr>
<td>Problem-centered idea uptake</td>
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<tr>
<td>Synthesizing notes</td>
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<tr>
<td><strong>Metacognitive</strong></td>
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<td>Shared Meta-discourse</td>
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<tr>
<td>Creating awareness</td>
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<tr>
<td>Major review</td>
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<tr>
<td>Deepening inquiry</td>
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</tbody>
</table>
discourse that revealed the students’ high-level shared epistemic agency in each phase, as shown in Table 2, to illustrate the development of the students’ shared epistemic agency.

Table 2 shows a gradual increase in the occurrence of notes in the categories of Ideation, Community, and Meta-discourse over the three stages in both the experimental and comparison classes. Table 2 also shows minor differences in the comparison class and significant differences in the experimental class in higher level discourse moves between the three stages. Primarily, the experimental students in the later stages generated more notes with explanations and rise above, developed a stronger awareness of community, and were involved in more activities, such as collective idea negotiation and synthesis to advance community knowledge, compared with those in the previous stage. The experimental students engaged more in shared regulative activities (e.g., conducting major reviews and reflecting on and extending community ideas) in the latter stages than the earlier stages. The results suggest that the students in the experimental class progressively took on higher level shared epistemic agency via AsCRA.

Students’ engagement in high-level shared epistemic agency by collective reflective assessment

We report the key events to demonstrate the process of enacting high-level shared epistemic agency in KB through AsCRA. The following gives some examples from the students’ analyses and reflections from their prompt sheets on how the use of PIT and KBDeX data guided their reflections.

Collective reflective assessment using PIT engaging students in negotiation of community ideas

The following narrative from the PIT prompt sheet by the student group inquiring on metacognition illustrates how reflective assessment using the PIT helped the students to engage in negotiating their ideas:

“We re-analyzed the ideas selected (by PIT, in the idea aggregation window, see Figure 1) to identify really promising ideas (to export in a new workplace using the export button), to organize our thoughts, and to prepare for our next stage of inquiry. The analysis was a reflection and summary of our inquiry and discussion in the first stage... After analysis, we found that our discussion on metacognition centered around the following four aspects (Figure 6). Although we have some initial understanding about metacognition, our discussion is somewhat superficial... there is little discussion on how to deploy and develop metacognition... We need to improve our discussion in each aspect... to refine the theories and contextualize application in a more suitable scenario... We will use the following plan to deepen our inquiries (Figure 6)...”

In this excerpt, the students reflectively analyzed their ideas in the idea aggregation window of the PIT with a specific purpose (“to identify really promising ideas, to organize our thoughts, and to prepare for our next stage of inquiry, a reflection and summary”). This offered useful insights, as the students had the sense that negotiating between diverse ideas and organizing and refining their discussion lines with logic were important. Throughout the analysis, the students identified key issues (“our discussion on metacognition centered around the following four aspects,” “our discussion is somewhat superficial... there is little discussion on how to deploy and develop metacognition”). Based on their analysis, the students generated an inquiry plan for the next stage (Figure 6). The above excerpt suggests that PIT-supported reflective assessment helped the students to assume high-level shared epistemic agency. The students identified their problems and regulated their efforts toward one promising direction of discussion, enhancing their understanding of how to apply the theories of metacognition to a more suitable scenario (Figure 6), and further generated projective plans. Tracking the students’ progress from Figure 6(a) to Figure 6(b), it was noted that the students extended their projective plans by incorporating more details. They identified “specific methods” and “scope” as their major focus and contextualized each branch within specific scenarios. Moreover, the students figured out roles that might be important to...
Table 2: Changes of high-level shared epistemic agency: frequency and percentage of different categories of epistemic and regulative dimensions in the experimental and comparison classes in Stages 1, 2 and 3

<table>
<thead>
<tr>
<th>No. of notes in each stage</th>
<th>Stage 1</th>
<th>Stage 2</th>
<th>Stage 3</th>
<th>Stage 1</th>
<th>Stage 2</th>
<th>Stage 3</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>f</td>
<td>%</td>
<td>f</td>
<td>%</td>
<td>f</td>
<td>%</td>
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<tr>
<td><strong>Epistemic</strong></td>
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<td></td>
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</tr>
<tr>
<td>Questioning</td>
<td>42</td>
<td>11.17</td>
<td>24</td>
<td>6.37</td>
<td>16</td>
<td>4.26</td>
</tr>
<tr>
<td>Explanation-seeking</td>
<td></td>
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<tr>
<td>Ideation</td>
<td>236</td>
<td>62.77</td>
<td>285</td>
<td>75.60</td>
<td>323</td>
<td>85.90</td>
</tr>
<tr>
<td>Rise above</td>
<td>13</td>
<td>3.46</td>
<td>33</td>
<td>8.75</td>
<td>47</td>
<td>12.50</td>
</tr>
<tr>
<td>Community</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Negotiating a fit</td>
<td>171</td>
<td>45.48</td>
<td>193</td>
<td>51.19</td>
<td>192</td>
<td>51.06</td>
</tr>
<tr>
<td>Problem-centered idea</td>
<td>69</td>
<td>18.35</td>
<td>86</td>
<td>22.81</td>
<td>113</td>
<td>30.05</td>
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<tr>
<td>uptake</td>
<td></td>
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<tr>
<td>Synthesizing notes</td>
<td>14</td>
<td>3.72</td>
<td>35</td>
<td>9.28</td>
<td>51</td>
<td>13.56</td>
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<tr>
<td><strong>Regulative</strong></td>
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<td></td>
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<tr>
<td>Shared Meta-discourse</td>
<td>55</td>
<td>14.63</td>
<td>59</td>
<td>15.65</td>
<td>28</td>
<td>7.45</td>
</tr>
<tr>
<td>Creating awareness</td>
<td></td>
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<tr>
<td>Major review</td>
<td>7</td>
<td>1.86</td>
<td>13</td>
<td>3.45</td>
<td>20</td>
<td>5.32</td>
</tr>
<tr>
<td>Deepening inquiry</td>
<td>6</td>
<td>1.6</td>
<td>21</td>
<td>5.57</td>
<td>29</td>
<td>7.71</td>
</tr>
</tbody>
</table>
promote their metacognitive skills and with specific strategies. They raised questions to guide their future discussions, which made their action plan plausible.

Collective reflective assessment using KBDeX data engaging students in synthesis and rise above of communities’ ideas

The following excerpt from a KBDeX prompt sheet demonstrated how reflective assessment with the KBDeX data (Figure 3) helped students to assume high-level shared epistemic agency:

Figure 6: Students’ artifacts demonstrating reflective assessment. (a) Students’ analysis and organization of their ideas, (b) Students’ plan of next stage of their inquiry. Note: Figure (a) and (b) were reproduced and translated from Chinese into English
We hope to summarize what we have discussed and further improve our discussion... With the help of the two graphs (after analysis of the two graphs generated by KBDeX, Figure 3), we can find that our discussion on critical thinking primarily focuses on four aspects that were the measurement, development, application and reflection and critique, and our KF inquiry seems quite good. We discussed well on how to measure critical thinking and how to critique... our discussion on how to develop students' critical thinking and effectively use critical thinking are kind of superficial... We can deepen our inquiry in next round by further discussing collective critical thinking, in particular metacognitive reflection and teaching belief of critical thinking; the ideas located far from the center and some students have discussed them, but they are critical for developing and effectively using critical thinking.

In this narrative, one student group reflected on the inquiry on critical thinking using the graphs from KBDeX focusing on (“summarize what we have discussed and further improve our discussion”). This showed encouraging insights as the students noticed that synthesizing and extending ideas were important. Using the graphs, the students identified the issues that were (“... measurement, development, application and reflection and critique,” “discussed well on how to measure critical thinking and how to critique...” and “discussion on how to develop students’ critical thinking and effectively use critical thinking are kind of superficial...”). Based on the analysis, the students appeared to reflect on the quality of lines of inquiry and the gaps, and generated action to address the gaps that were (“deepen our inquiry in next round by further discussing collective critical thinking, in particular metacognitive reflection and teaching belief of critical thinking”). It was encouraging to see that the students reviewed the ideas located in the periphery and identified promising ideas to advance their inquiry iteratively rather than ignore the ideas.

Overall, these results suggest that students engaged in high-level shared epistemic agency by carrying out AsCRA. The reflective assessment helped students connect their learning orientation with the important goals of KB (eg, idea negotiation, synthesis and rise above), productively and reflectively assess their discussion, and further regulate their discussion by generating productive plans.

**Discussion and implications**

In this study, we provided a KB design, augmented by AsCRA, to help undergraduates in continuously developing high-level epistemic agency during the KB process. We aimed to examine the impacts and the processes of analytics-supported reflective assessment in fostering high-level shared epistemic agency among undergraduates.

*Impacts of analytics-supported reflective assessment on students' shared epistemic agency*

A comparison of the frequency with which students distributed notes showing high levels of shared epistemic agency indicated that the students in the experimental class engaged in more epistemic and regulative actions than students in the comparison class. Furthermore, students in the experimental class demonstrated a significant gradual increase in both epistemic and regulative actions from the beginning to the end of their KB. These results suggest that analytics-supported reflective assessment in the KB model can help students to take increasingly higher levels of shared epistemic agency in KB inquiries. These findings are consistent with prior research that has examined KB inquiry and reflective assessment (Raes, Schellens, & De Wever, 2014; White & Frederiksen, 1998; Yang et al., 2016, 2019). The findings also support previous research on the positive effects that analytics have on productive KB inquiry and knowledge creation (Chen, 2017), and on analytics-supported reflective assessment and epistemic agency in KB (Yang, 2019). This study has provided an example of the potential that KB design, augmented by collective reflective assessment, has for facilitating high-level shared epistemic agency, in a cultural and educational context that places great emphasis on examinations. The study also has
theoretical value, as it offers insights into the relationships between collaborative inquiry, agency, assessment and instructional practice.

KB theory postulates that group members add value to knowledge creation. This theory also emphasizes the scaffolding function of “embedded and transformative assessment” (Scardamalia & Bereiter, 2006). The KB design, when enhanced by AsCRA, can make this process explicit for people engaged as knowledge builders in collaborative inquiry, idea improvement and continual reflection. This design has important implications for the development of technology-rich environments to support learners, and it offers insights for teachers seeking to use such environments in helping learners to attain increasingly higher levels of epistemic agency.

**Students’ engagement in high-level shared epistemic agency through collective reflective assessment**

Qualitative analysis of the students’ prompt sheets revealed that the use of analytics (PIT and KBDeX) with accompanying prompt sheets fostered the students’ engagement in high-level epistemic agency. This approach involved the students in ongoing collective reflection on idea negotiation and synthesis. The approach also helped them to engage in rise above community ideas, analysis of issues and gaps in the KB inquiry and action planning for the next round of KB inquiry. The results suggested that conducting analytics-supported reflective assessment can drive students to gradually deploy and develop their metacognitive skills such as goal setting, reflection, gap analysis and action planning. Such assessment can also help students to engage in reflecting and regulating their collective KF discussions, thereby participating in increasingly higher levels of shared epistemic agency in the KB process.

In this study, we provided students with data and evidence on their inquiries by including analytics to promote more productive collective reflective assessment. We also designed prompt sheets to guide the students’ productive reflective assessments with the use of analytics. The prompt sheets consisted of a metacognitive model (eg, “Our analysis,” “Our issues,” “Our plan”), and a set of specific metacognitive prompts that scaffolded students to engage in metacognitive processes such as the reflective assessment of the KB inquiry and of ideas using analytics data, the analysis of gaps and action planning for further KB inquiry and knowledge creation. By engaging in collective reflective assessment, the students gradually internalized the metacognitive model. They identified issues and took actions to address issues. Such activities are crucial for developing high-level shared epistemic agency. The analytics data and the accompanying prompt sheets for a metacognitive process in the KB model proved to be critical for enabling productive collective reflective assessment, and thus the development of epistemic agency.

In addition, we highlighted the teacher’s role in designing the KB environments and in scaffolding the process of KB inquiry through analytics-supported reflective assessments. The teacher created a collaborative ethos, with norms to encourage the students’ democratic participation and to help them build a sense of community. Moreover, the teacher used analytics to create a hybrid learning environment. This environment involved face-to-face KB inquiry, which was enhanced by KF online inquiry to support the students’ inquiries and epistemic agency. Furthermore, the teacher demonstrated a strong belief that KB design, when enhanced by collective reflective assessment, could motivate and help the students to engage in epistemic agency.

**Implications for educational practices to empower students as active agents**

The findings of this study have several implications for teachers seeking to help their students in developing agency and the high-level competencies needed for students’ empowerment of self-directing and taking control of their own learning. First, it is important to create a collaborative-metacognitive culture for KB inquiry and knowledge creation. This culture can be enabled
by fostering a sense of community and community identity among the students, and by helping them to actualize metacognition. According to this culture, the students and teachers, as active agents, seek to inquire and learn together. They reflect and regulate their inquiries together and build knowledge together. Everyone’s ideas are important to the community, and everyone needs to make contributions to advance their collective understanding. Every idea can be improved progressively. Second, it is important to help students in developing a productive belief that the process of reflecting and improving ideas should be iterative, and that continuously improving ideas is critical. Third, analytics-based reflective assessment can greatly benefit students. However, opportunities for collaborative reflection are needed to help students engage in meta-level KB discussions that mix online inquiry with offline reflection, and that conduct productive collective reflective assessment using analytics with accompanying prompt sheets.

Limitations and implications for future research
This study has several limitations. First, we did not make full use the full set of classroom data sources such as student artifacts, face-to-face discussions and video-recordings of classrooms. To provide a clear account of KB, it is necessary to understand the relationship between online discussion and the dynamics of social practices as developed in the KB process. Therefore, further studies are needed to examine the classroom data sources, and to unpack the dynamics of the KB social practices by which collective reflective assessment can be productively carried out in KB inquiry and knowledge creation.

Second, the study focused on discourse, and did not examine changes in the domain knowledge of individual students. The findings provide evidence of higher level shared epistemic agency and its development over time, but it is unclear whether those changes are transferable. Further studies are needed to investigate the extent to which KB and reflective assessment prepare students for future learning or KB in other domains.

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Statements on open data, ethics and conflict of interest
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. This research has no conflicts of interest.

References


**Supporting Information**

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