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Learning Analytics for Teacher Noticing and Scaffolding: Facilitating Knowledge Building Progress in Science

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Abstract: This study investigates using ongoing learning analytics to support two teachers' reflective noticing and responsive scaffolding in knowledge building communities. Students in four Grade 5 science classrooms collaborated to investigate the human body systems for four months using an online platform: Idea Thread Mapper (ITM). The teachers kept weekly reflective journals to attend to students' collaborative idea progress and interpret the noticed events in order to make responsive moves to facilitate student knowledge building. Their reflective efforts were supported by knowledge building analytics. Qualitative analyses of the teachers' reflective journals, classroom and online discourse, and interviews traced how the teachers engaged in and facilitated students' knowledge building over time. The teachers used the analytical feedback to enhance their reflective attention and sense-making focused on students' idea-growing efforts as individuals, groups, and a whole community, including discovering student inquiry moves, reforming collaborations, and intertwining analytical feedback into iterative noticing and scaffolding.

Introduction

To prepare students for a rapidly changing world with complex challenges, education needs to create an adaptive and creative learning culture that empowers student-driven inquiry and collaborative knowledge building. Recent research on computer-supported collaborative learning (CSCL) calls for more dynamic and transformative designs of collaborative inquiry in which students take on creative roles to co-construct shared knowledge goals, processes, and spaces (Damsa et al., 2010; Hakkarainen, 2009; Kali et al., 2015; Tao & Zhang, 2021). Students engage in ever-deepening inquiry, building on what they have explored/learned in the past to advance their current work while identifying problems and directions for further inquiry. Implementing student-driven inquiry and dynamic collaboration requires teachers to adapt their roles in the classroom. Research suggests the balancing act of teaching for student-driven inquiry: The teacher needs to *act in* (immerse in) students' collaborative inquiry and discourse as a co-learner in order to *act on* (intervene) the evolving flows of thoughts and activities through timely and responsive scaffolding, which builds on and further enhances student-initiated efforts (Richardson, 2013; Zhang et al., 2011, 2018). The current study investigates how two teachers played such role in grade 5 science classrooms that adopted Knowledge Building (KB) pedagogy (Scardamalia & Bereiter, 2014), a model of CSCL innovations for creative education. The analysis sheds light on the teachers' reflective noticing of students' ongoing inquiry progress that guides the teachers' responsive scaffolding, supported by classroom-based learning analytics. The analytics trace students' knowledge building discourse and generate ongoing feedback on emerging interests, idea progress, and inquiry needs/gaps.

Teachers' noticing and scaffolding in knowledge building communities

KB pedagogy aims to transform classrooms into knowledge building communities where students "produce ideas of value to others and share responsibility for the overall advancement of knowledge in the community" (Scardamalia & Bereiter, 2010, p. 80). A set of knowledge building principles was used to guide dynamic classroom processes (Scardamalia, 2002). Principles relevant to the current research include: (a) Knowledge building evolves around students' *authentic problems and genuine ideas*. (b) The process of inquiry is not only to discover the standard "correct" answer to a question but to pursue *continual idea improvement*. Students take risks to share tentative "half-baked" ideas, give and receive critical feedback, and work individually and collaboratively to improve and revise their theories and solutions. (c) Students are responsible for their learning and further take *collective responsibility* for advancing their community's knowledge as a social product. (d) The teacher works with students to monitor their ongoing work through *concurrent and transformative assessment*, producing constructive feedback that informs the continual deepening and expansion of inquiry. The collaborative discourse in the classroom and online is characteristic of collaborative emergence and improvisation driven by all the participants through interactive input (Zhang et al., 2011).

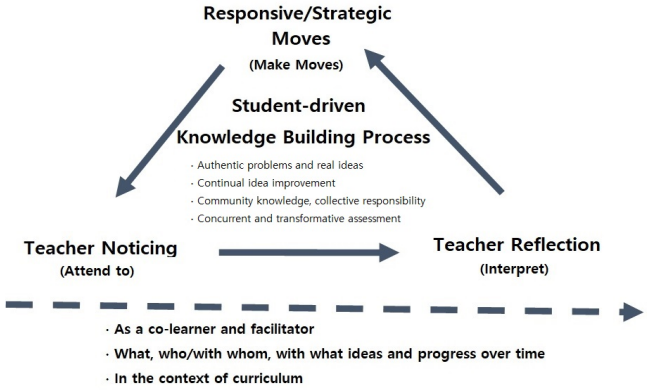
Existing studies underline the role of the teacher as a knowledgeable co-learner and partner (Tabak & Baumgartner, 2004; Zhang et al., 2011), who participates in the knowledge building process with students while

seizing opportunities to catalyze productive thinking and deepen/expand student understanding in connection with the curriculum goals. Related to the new dynamics of teaching, a growing line of research investigates teacher noticing: their reflective observation and analysis of classroom processes that inform responsive teaching (Hammer & van Zee, 2006; Luna, 2018; Robertson et al., 2016). Several interconnected elements of teaching noticing have been identified, including (a) detecting important information about the classroom going-on, (b) analyzing and interpreting what the information means with respect to learning goals, and (c) deciding how to respond to further student learning (Barnhart & van Es, 2015; Jacobs et al., 2010; Luna, 2018). Aligned with the concept of teaching noticing, researchers are testing technology support (e.g., teacher dashboard) to help teachers track and analyze student thinking in CSCL settings (van Leeuwen et al., 2019). While existing research on classroom orchestration has focused on how the teacher manages multi-layered activities in a multi-constraints context (Dillenbourg, 2013), research on teacher noticing offers a learner-centered lens to understand how the teacher improvises in response to students' ideas, foregrounding student agency for ever-deepening inquiry.

Drawing upon the literature, we propose a framework to guide the study of teacher noticing for knowledge building with analytics support (see Figure 1). The central focus and goal of teacher noticing are directed toward student-driven inquiry and discourse by which the community continually advances collective knowledge and personal understanding. Three key elements are highlighted, interweaving the teacher's classroom attention (A), interpretation (I), and pedagogical moves (M) (A-I-M). The teacher (a) attends to children's evolving ideas and inquiry practices to detect dynamic information about what is going on and what is new and emerging; (b) interprets the classroom information to understand how students are thinking now in relation to their work in the past and potential idea development in the future as informed by teacher experience and curriculum knowledge; and, based on the evolving classroom situation; and (c) envisions possible strategic moves (choices) to further leverage student knowledge building. The above-noted core knowledge building principles guide strategic attention, interpretation (meaning-making), and decision-making.

Figure 1

Principle-Based Reflective Noticing and Responsive Scaffolding for Knowledge Building



Analytics for knowledge building

In a classroom featuring student-driven inquiry and improvisational discourse, it is challenging for the members (teacher and students) to trace and make sense of what is going on in student collaborative and personal work that evolves over time. To address this issue, researchers explore learning analytics for knowledge building, drawing upon earlier works on analytics tools for research use (e.g., Oshima et al., 2012). Chen and Zhang (2016) propose two principles for guiding analytics design in this context. First, analytics for knowledge building should detect key aspects of continual idea progress, drawing upon multi-level and multi-timescale data produced in progressive discourse. The progressive changes may include the development of conceptual depth and breadth in existing inquiry topics and the emergence of new strands of inquiry based on students' interests. Second, analytics for knowledge building need to inform epistemic choice-making by members of the community, focusing on enhancing student agency. Example epistemic choices and moves include determining promising ideas in existing areas as the foci of purposeful inquiry efforts (Chen et al., 2015), initiating a new line of inquiry based on an emerging theme and form a spontaneous group (Zhang et al., 2018), and engaging in shared regulation on collaborative processes using analytics feedback (Wise et al., 2015). The learning analytics tools may dive into students' improvisational discourse to capture emergent inquiry and contributions. With this data-driven feedback,

teachers can work with their students to better monitor evolving ideas, questions, and connections and direct their knowledge building progress (Chen & Zhang, 2016; Zhang, 2019).

Purpose of this study

The present study aims to explore teachers' reflective noticing and responsive scaffolding in a set of Grade 5 knowledge building communities, supported by ongoing analytics feedback that traced the temporal progress of students' collaborative discourse. The teachers kept weekly journals for reflecting on knowledge building progress and envisioning further opportunities and actions for knowledge building. Our research team provided the teachers with weekly analytic reports to trace idea progress and inform epistemic moves. The teachers referred to the provided analytics when writing their reflective journals. The research questions included: (a) How did the teachers engage in ongoing reflection supported by learning analytics during the knowledge building process? (b) What aspects of the knowledge building practice did the teachers attend to in their reflective journals with the analytics support? (c) How did the teachers interpret the knowledge building situations and envision responsive moves? And (d) How were the envisioned moves adopted/adapted in the subsequent classroom interactions to further student knowledge building?

Method

Classroom settings

This study was conducted in four Grade 5 science classrooms with 83 students at a public elementary school in the northeast US. Two teachers (Mrs. G and Mrs. T) taught the science curriculum, each teaching two classrooms. While both teachers had multiple years of teaching experience, Mrs. G was in her sixth year, and Mrs. T was in her first year of teaching using KB pedagogy. Data collection from the two teachers allowed us to understand how learning analytics may be used by teachers with different levels of experience.

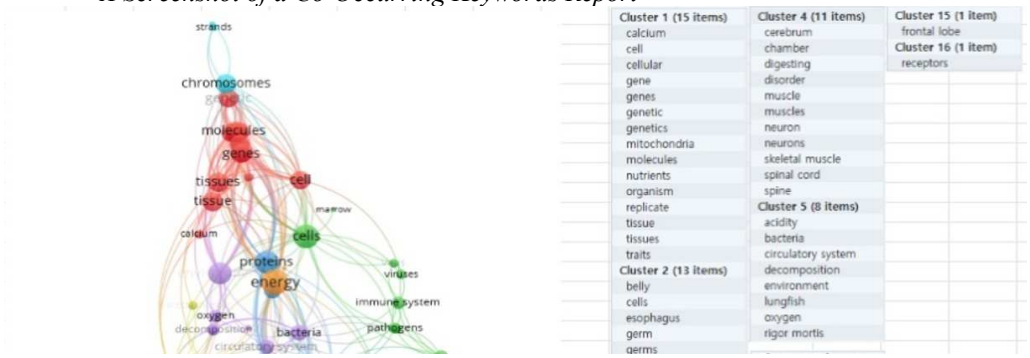
As part of the science curriculum, the students studied the human body system over a four-month period. The science inquiry was organized following the principles of KB (Scardamalia, 2002). Specifically, the inquiry was kicked off with a set of hands-on activities that stimulated student interests and questions about how the human body works. Through sharing and co-reflecting on the personal questions, students formulated a set of *wondering areas* (inquiry directions), including how the human body gets energy from food, how blood travels through the body, bones and muscles, how the brain works, and so forth. The students carried out extended inquiries using resources while continually generating deeper and new questions. Their inquiry work integrated personal inquiry, group work, and whole-class discourse. As a specific type of conversation, students engaged in *metacognitive meetings* that focused on reviewing questions and ideas, evaluating collective progress, and planning for deeper inquiry work. The classroom discourse was extended online through Idea Thread Mapper (ITM), a visual online platform for collaborative knowledge building. In ITM, the teachers set up the *wondering areas* as collaborative spaces based on students' interests and questions. Students posted and built on one another's notes to advance the online discourse in each area. The discourse was visualized in a two-dimensional space based on a timeline and student authors; thus, the classroom members could easily trace temporal progress and student participation. An activity radar in ITM showed basic statistics about student participation online in each wondering area.

Knowledge building analytics to support teacher noticing

In addition to the visualization and analytic information embedded in ITM, the researchers generated integrated analytic reports to trace students' knowledge building progress over time. Guided by the principles of analytics for knowledge building (Chen & Zhang, 2016), the analytic reports used a set of measures to trace ongoing idea progress in each classroom community and inform possible epistemic needs and actions. The idea progress tracking included information about the evolving scope and depth of student inquiry based on data retrieved from student collaborative discourse and individual work (e.g., notebooks). On a biweekly basis, the first author generated an analytic report for each classroom using a set of analytic tools. Text analysis and Social Network Analysis were conducted over ITM notes. *Vocabprofile* (Cobb, 2019) was utilized to trace student use of academic words (Coxhead, 2000) and special terms. A network of co-occurring word clusters was created using *KBDeX* (Oshima et al., 2012) and *VOSviewer* (CWTS Leiden, 2019), visualizing the landscape of knowledge structures (Eck & Waltman, 2011; Su & Lee, 2010). The analytic reports integrated information generated from these tools to trace (a) students' cumulated ITM notes about "big ideas" in each wondering area and (b) emerging ideas and interests for further inquiry, and (c) core student contributors. Figure 2 shows a report that captured a cluster of discourse related to cells and tissues in the human body using a co-occurring keyword map. In the visualization, co-occurring keywords are linked by lines in different colors, forming clustered networks. Each cluster has co-

occurring keywords and captures a potential conceptual theme. By referencing such reports, the teachers noticed emerging concepts that the students mentioned in their online discourse. They also checked these reports while writing their weekly reflective journals and planning the following lessons.

Figure 2
A Screenshot of a Co-Occurring Keywords Report



Data sources and analysis

Teachers' reflective journal

The primary data source was the two teachers' reflective journals. Mrs. G and Mrs. T used a reflective journal template to guide their reflection and writing. The template included three columns set up based on the Attend ("I notice……"), Interpret ("I think……"), and Make Moves ("In the coming week……") framework (A-I-M, Zhang, 2019). A total of 31 reflective journals was collected from the two teachers, with 74 entries (rows) of reflection each involving a A-I-M set. These A-I-M sets were arranged chronologically based on time of creation for the data analysis. The reflective journal entry was initially analyzed using the grounded theory approach (Strauss & Corbin, 1998) to understand what aspects of student inquiry the teachers attended to, how they interpreted, and the classroom moves they envisioned. The first author read the reflection journals multiple times to develop a general sense of the teachers' reflection. Then, she worked with the second author to develop initial open codes using a subset of reflection journals. The two co-authors then discussed the open codes and the related examples, reflected on the meaning and consistency of the codes, and refined the labels and definitions. Based on the discussion, a codebook was generated and then used to code the whole set of reflection journals. Based on the coding, we further searched for connections between the codes to form themes representing the teachers' points of noticing and ways of interpreting supported by the analytics feedback, thereby addressing the first two research questions.

Face-to-face and online knowledge building discourse

To investigate the last two research questions, we analyzed the observational records of students' inquiry and discourse in the classroom and their online discourse in ITM. A researcher observed each science lesson and video/audio-recorded the major inquiry activities such as the metacognitive meetings. The authors selected the records of metacognitive meetings and ITM discussions that were closely related to the teachers' noticing and planning recorded in their reflection journals. The authors reviewed the teachers' reflective journals, idea tracking reports, and observation field notes to choose highly relevant classroom episodes and ITM discourse. Using a narrative approach (Butina, 2015), the selected moments were analyzed by tracking the flows of the teachers' noticing points, scaffolding moves, and students' actual actions captured in the classroom and online data. Through this process, we constructed storylines of how the teachers observed and interpreted the different scenarios of student knowledge work in the classroom and online, envisioned responsive pedagogical moves, and worked with students to further their inquiry and collaboration.

Interview of teachers and students

The above data analyses were further enriched with data from the teacher and student interviews conducted at the end of the science unit. A researcher interviewed the two teachers individually, each using approximately 40 min. Semi-structured interview questions were used to understand the their experiences of reflective scaffolding of knowledge building with the support of discourse analytics. We also interviewed students to understand their experience with knowledge building. The interview was video/audio-recorded and fully transcribed for a qualitative analysis.

Findings

Teachers' ongoing reflection with knowledge building analytics

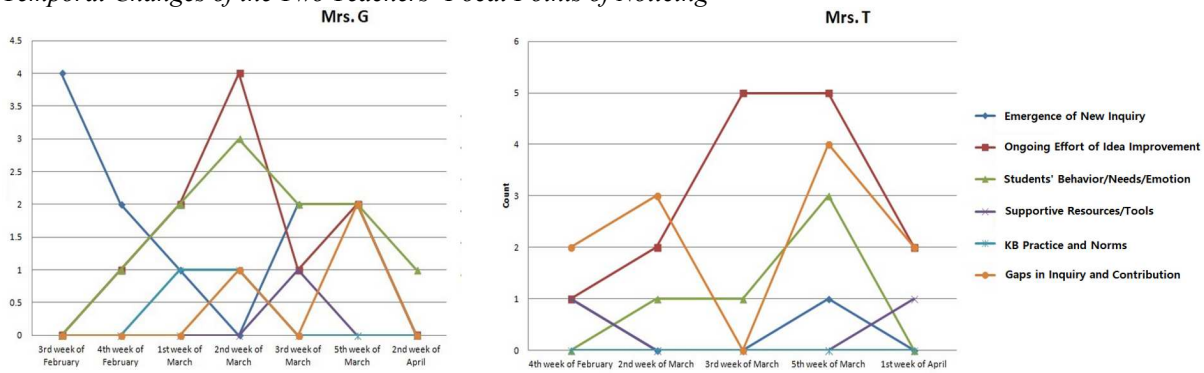
The two teachers consulted the analytics support to monitor students' inquiry progress and reflect on emergent interests and needs, so as to scaffold further knowledge building work that generated new data for their subsequent reflection. When writing reflective journals, the teachers typically started from "what students did and just moving from there." According to Mrs. G, she read students' ITM notes and her classroom memos, which she jotted down on paper sheets when observing student works in the classroom, to find important conversations and students involved. With the ongoing analytical feedback, the teachers noticed new knowledge advances, promising inquiry questions, and directions for deeper work together with the major student contributors in these inquiry areas. They also attended to underdeveloped inquiry areas needing more active involvement and advancement. In the interview, Mrs. G said that such reflection was helpful for her to figure out the conceptual prepress and gaps in order to help students go deeper with their inquiry. Regarding the use of the analytics support for noticing, Mrs. T mentioned that it was helpful to get to the core point of students' enormous collaborative discourse and find the missing inquiry area that students needed to dive into more deeply. As she said, *"I use them a lot and my teacher reflection. It really helped me to weed through millions of posts on ITM to just get to the best stuff."* She also talked about utilizing the analytics support to trace students' contributions in inquiry areas: *"But I also really made a lot of use of the graphics showing who was posting in which areas."* The teachers' reflection with the analytical feedback informed their planning and scaffolding for high-potential knowledge building moves. Sometimes, the two teachers co-reflected on what was going on their classrooms and engaged in shared planning. As Mrs. T mentioned: "*Because Mrs. G and I use that [the idea tracking reports] a lot… So we used those overarching graphs to say, "Okay, so here's where nobody really is. Maybe, we should play up that area a little bit*." The teachers then scaffolded the next knowledge building moves in their classrooms independently and collaboratively. The teachers' scaffolding aimed to leverage students' collaborative idea progress in the needed areas. As Mrs. G mentioned, she typically asked herself: "What does the students need? Or how can this help the rest of us (class members)?" They also attended to the students who needed to keep up with the progression of the communities. Part of their scaffolding was to engage students in the periphery more deeply in the knowledge building communities toward the core areas.

What aspects of the knowledge building practice did the teachers attend to?

The analysis of the reflective journals (e.g., entries in the Attend column) identified the teachers' focal points of noticing. Overall, the teachers often monitored ongoing efforts of idea improvement in existing lines of inquiry while detecting gaps in student inquiry and contribution. We further traced the teachers' focal points of noticing over time across the different phases of the human body inquiry (see Figure 3).

Figure 3

Temporal Changes of the Two Teachers' Focal Points of Noticing



In Mrs. G's case, she paid attention to new inquiry directions at the beginning of the science unit and increasingly monitored students' ongoing progress in the existing lines of inquiry and their emergent needs. Mrs. T also monitored students' progress in the existing lines of inquiry and their participatory behaviors. Compared to Mrs. G, however, Mrs. T more often detected student gaps in inquiry and contribution using the analytical feedback throughout the human body unit. Specifically, the teachers used the analytics reports to monitor progress and gaps in students' individual and collective inquiry contributions. On the collective level, the analytical feedback informed the teachers about inquiry areas with new progress as well as those the community had rarely

engaged in. On an individual level, the analytics support captured student contribution of high-quality notes about any core concepts in the collaborative discourse in ITM. The teachers became more alerted to students' deep and high-potential ideas that they might otherwise miss without the analytic feedback. In the same way, the teachers used the analytics support to monitor potential gaps in student inquiry and contribution in the classroom online and, over time, to trace students' further contributions to addressing the gaps. In the subsequent weeks, the teachers revisited the gaps and issues that they had captured in their previous reflective noticing. By doing so, they could trace each student's progress continuously and facilitate his/her inquiry work, peer connections, tool use, or trace the work of a group that they had reflected on so as to facilitate deeper collaborative work.

How did the teachers interpret their noticing points and envision responsive moves?

Our analysis further identified how the teachers analyzed and interpreted what they had noticed for pedagogical sense-making. Several themes emerged, each representing a pattern of pedagogical thinking, including: (a) making sense of the progress and value of students' ideas in shared discourse and personal works (n = 11, 14.86%); (b) understanding students' intents of inquiry, needs of resources/tools, or emotional experiences as individuals, groups, and a whole community (n = 30, 40.54%); (c) reflecting on gaps and challenges in student inquiry and contribution (n = 9, 12.16%); (d) analyzing opportunities to connect different concepts and inquiry areas (n = 7, 9.46%); (e) analyzing opportunities/needs to expand the scope of collective inquiry (n = 3, 4.05%); (f) analyzing opportunities/needs to deepen existing inquiries (n = 1, 1.35%); and (g) reflecting on how KB practices and norms had been functioning such as student participation in classroom and online discourse (n = 2, 2.70%).

Drawing upon their pedagogical sense-making of student knowledge work, the teachers envisioned responsive moves to be facilitated and enacted in the classroom or online. The most frequent pedagogical moves included: (a) addressing students' needs (e.g. resources/tools/peer connections) to improve their inquiry and learning experience (n = 13, 17.57%); (b) facilitating idea connection and student collaboration (n = 13, 17.57%) such as by raising student awareness of the related ideas/works from their peers or matching a few students to form a group; (c) forming new inquiry directions with students (n = 11, 14.86%), such as by highlighting a student's question or early work in a new area to stimulate students' interests or pointing out a missing/underdeveloped inquiry area to encourage more contribution; (d) facilitating deeper inquiry/discourse (n = 8, 10.81%) by encouraging the ongoing inquiry of individuals while improving KB practices and resources, or by nurturing collaborative discussion in the classroom and online for continual idea deepening; and (e) facilitating the spread of inquiry progress (n = 6, 8.11%) such as by featuring new progress made by individuals/groups in the classroom. As a specific follow-up action, the teachers also recorded specific plans to for further classroom observation attending to students' subsequent contribution, collaboration, and inquiry directions (n = 4, 5.41%).

Therefore, our analysis further traced the interconnected temporal flows of the teachers' noticing, reflection, and scaffolding across the weeks of the human body inquiry. The analysis revealed the iterative processes they engaged in to observe, think, envision, act/interact with students, and observe again. For example, based on their reflection on gaps and needs in a week, the teachers wanted to further students' inquiry and idea connection. In the following weeks, they attended to and reflected on student collaboration and sharing with the support of the analytical feedback. When the reports showed that students had little progress in an inquiry area, they thought about its reason and pinpointed student needs for support. They planned ways to better engage the less-engaged students or connect individual students into small groups to work on the underdeveloped concepts and share their knowledge with the community. They also decided to highlight the missing concepts in metacognitive meetings and facilitate idea connections. In a subsequent week, the analytics report showed a student's high-quality ITM note related to these concepts. The teachers analyzed the progress made and assessed the potential to use it to further enrich collective understandings in classroom conversations. Therefore, they envisioned inviting the student to share the note in classroom conversations and fostering other students' idea build-ons.

How were the envisioned moves adopted/adapted in the subsequent interactions?

This section reports the analysis of the teachers' subsequent actions in the classroom after envisioning how to scaffold KB with the analytics support. It zooms into the cyclical patterns of how the teachers implemented the responsive scaffoldings and conducted further noticing as adopting the analytical feedback and how individual and collective students responded to the teachers' scaffoldings.

A good example was when Mrs. T recalled stunning moments of finding three students across classrooms and envisioned reformation of the collaborative opportunities among these students. Eva (from Mrs. T's class), Tom (Mrs. T's), and Bella (Mrs. M's) were in good progress about diseases with decent ideas and questions. On March 10th, Mrs. T firstly noticed that Bella, Eva, and Tom raised smart questions about diseases and wrote about that in her reflective journal. She felt that Eva's deep knowledge would be beneficial for advancing the other two

students' knowledge and envisioned getting them together to have a small group discussion. The following idea tracking report on March 24th captured Bella and Tom as core contributors to the area of disabilities/disease as they were talking about "insulin" and "diabetes." What was more, Mrs. T had a continuous interest in these three students' possible collaboration, returning to her prior reflections throughout the course. After a couple of weeks, she reminded her envisioning when Tom was back to class from his absence. Finally, on April 1st, she pulled these students in a group to the back of her homeroom classroom. During the meeting, the teacher participated as a facilitator by explaining, asking, responding, and encouraging students to connect their own learning topics to each other's knowledge.

In the interview at the end of the school year, these students reflected on Mrs. T's instruction and facilitation of their collaborative learning. The students compared the teacher's instruction and their learning this year with those of last year, pointing out that they could have more freedom to follow their own dynamic inquiry moves this year. While students were focusing on their individual and collective inquiry progress, the teacher helped them deepen and expand ideas by providing useful resources when they got stuck during learning progress. Further, the teacher not only supported the individual students' idea progress but their collaboration for building ideas on similar inquiries. For these students, for example, that was the moment when Mrs. T found their possible collaboration and invited them to hold the small group meeting. Bella said, *"Well, if I had a question about something, like Mrs. T would tell me who else was doing my like, who else was doing diseases or diabetes, so that I could collaborate [with] them [Eva and Tom] and learn more about it."*

Discussion and conclusions

The present study adopted ongoing analytics feedback to support teacher noticing and scaffolding for KB. The results provided rich understandings of the teachers' noticing points in monitoring what was going on in a KB community, patterns of interpretation for pedagogical sense-making, and ways to make responsive scaffolding moves with students. The teachers consulted the analytics support while cyclically monitoring and envisioning students' inquiry progress based on student needs, improving classroom processes and re-shaping the collaborative knowledge building directions of the community.

Several key points are derived from the findings. First, the teachers integrated the analytics support into their iterative reflections. When the teachers accessed the idea tracking reports, they took notes of the most core point of the students' progressive ideas, emergent concepts, and contributions in collaborative discourse, which drove them to start from there to make responsive envisioning. Second, the primary, direct benefit of the analytics support was to show the teachers a summary of students' dynamic idea process. While the analytics support presented emergent inquiries over time, the teachers paid more attention to the progress, gaps and missing concepts in student discourse. Third, teachers' concurrent reflection with the analytics support paid additional attention to students' possible collaboration. It enhanced the teachers to foster collaborative knowledge building of individual students and groups, and eventually for the whole community. Fourth, Teachers sustained their pedagogical thinking and envisioning throughout the reflection processes. Regular, data-driven analytics support eased the teachers' reflective noticing and expedited the synthesis of their direct observations and analytical feedback. Consequently, the teachers were able to focus on their pedagogical reflection, sense-making, and responsive scaffolding. Then, they returned to their previous reflection, continued reflective noticing, and received further analytical feedback. This iterative process was integral to the teachers' classroom practice to support student knowledge building over the whole course.

The findings suggest that data-driven analytics support further promotes teachers' transformative assessment of students' collective idea progress. At the same time, it assists them in attaining reflective noticing and scaffolding of dynamic knowledge building processes. The understandings of teacher noticing, interpretation, and scaffolding provide an empirical base for designing analytics for knowledge building (Chen & Zhang, 2016).

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