Students Taking Charge at the Highest Levels: Cross-Community Engagement in Design Mode with Knowledge Forum Analytic Tools

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Abstract: One of the core aims of Knowledge Building is to move students toward higher levels of agency. The design challenge for Knowledge Forum is to provide supports "attuned to the self-organizing character of learning" through powerful feedback mechanisms that enable students to make reflexive and progress-oriented decisions that sustain collective knowledge advancement. This study follows three design iterations of metadiscourse with 8- and 11-year old students, culminating in a cross-community discussion of next-generation analytics for Knowledge Forum at the 2019 Knowledge Building Summer Institute. Through metadiscourse, students demonstrated sophisticated interpretations of their online activities with the Knowledge Forum analytic tools. Not only were they honest and open about receiving feedback through novel forms of data visualization, they were also aware of the potential limitations of these tools and offered thoughtful and insightful feedback for our engineers. Pedagogical and technological implications are discussed within the context of nurturing the emergence of new competencies, such as design thinking and computational literacy.

Introduction

Education for the Knowledge Age must shift from teaching students as passive receivers of knowledge to empowering them as active creators of knowledge (Bereiter, 2002; Tan, So, & Yeo, 2014; Chan et al., 2020). For more than three decades, Knowledge Building pedagogy and technology has been transforming the culture of teaching in schools so that students can assume higher levels of agency for creative knowledge work (Scardamalia & Bereiter, 1991; 1994; see Chen & Hong, 2016 for review). Toward that end, Knowledge Forum has been designed and refined over countless iterations with input from teachers, researchers, engineers, designers, and even students to facilitate sustained, creative work with ideas in K-12 classrooms. It should be noted that unlike typical educational technologies, Knowledge Forum aims to provide flexible, transparent, and customizable supports to enable students of all ages to design conceptual artifacts and pursue emergent, open-ended paths to advance collective understanding – such affordances range from contributing ideas in the form of multimedia objects (e.g., notes, drawings, videos, audio clips) to connecting ideas through build-ons and citations to reorganizing conceptual spaces by linking views and creating rising above views to visualizing collective progress on analytic tools.

The design challenge is to provide supports "attuned to the self-organizing character of learning" (Scardamalia & Bereiter, 2014) through powerful feedback mechanisms that enable students to make reflexive and progress-oriented decisions (Chen & Zhang, 2016) that sustain collective knowledge advancement. One form of effective feedback mechanism is metadiscourse, which involves metacognition, meta-theory, and meta-conversation (Lei & Chan, 2018). Past research conducted in school classrooms reveal that young students are capable of engaging in metadiscourse using the Knowledge Forum analytic tools. Moreover, they demonstrate the ability to self-organize in productive ways that advance community knowledge. For example, 7-year olds can reflect on the state of their community knowledge through comparative word clouds and use visualizations of expert vocabulary to improve their ideas and become a more discursively connected community (Resendes et al., 2015). 8-year olds can identify promising ideas in their discourse to revise existing ideas and pursue novel areas of interest that enrich the scientific sophistication of their community knowledge (Chen et al., 2015). 10-year olds can identify connections across inquiry threads on the Idea Thread Mapper and co-organize social structures based on emergent interests to channel more collaborative and productive knowledge practices (Tao & Zhang, 2018). These research advances have informed the latest iteration of the suite of analytic tools in Knowledge Forum (Scardamalia & Bereiter, in press), which support embedded assessment in daily classroom practices so that teachers as well as students can initiate metadiscourse during Knowledge Building. Table 1 provides an overview of some of these analytic tools from the perspective of researchers, teachers, and students that has resulted from our work together.

In this paper, we elaborate on three design iterations of metadiscourse in- and out-of classrooms with primary-age students. In the first iteration, Thelma used the word cloud tool with her grade 3 students (8-year olds) to reflect on their study of plants in science class. In the second iteration, Darlene used various analytic tools with her grade 6 students (11-year olds) to reflect on their study of humanitarian crises in social studies class. In the third iteration, Thelma's and Darlene's students worked together to explore each other's KF communities using the

analytic tools and discussed possible limitations and areas of improvement for the analytic tools at the 2019 Knowledge Building Summer Institute. These young students' intuitive design ideas and sophisticated interpretations of data visualizations are discussed in light of two major implications: technological implications for the design of next-generation Knowledge Forum analytics and pedagogical implications for nurturing the emergence of new competencies, such as design thinking (Martin, 2009) and computational literacy (DiSessa, 2018).

Design 1: Metadiscourse in Grade 3 Science

In the first design iteration, Thelma facilitated a metadiscourse session with her grade 3 class (n = 22) using the word cloud tool. After studying plants for a few months, students had written notes about how plants grow, plant roots, stems, and leaves, and the process of photosynthesis. Students also watched time-lapsed videos of beans growing and diagrammed their theories of how seeds turn into plants. As their discussions progressed, students became increasingly curious about the process of photosynthesis.

To address this emergent interest, Thelma showed her students a video that described the process of photosynthesis at the cellular level (generally shown in secondary biology class). Students then worked in half-groups to revisit their ideas and build on each other's notes and drawings with new scaffolds, such as "A new concept I learned", "A new fact I learned", "My improved theory is", and "I still need to understand". Figure 1a (top) shows that while the Sand group primarily focused on the concept of "stomata", the Clay group primarily focused on the concept of "water". Both groups had picked up the idea of "oxygen" from the video, but it was not as prominent in their discourse as it was in the expert discourse (bottom). During the metadiscourse session, the whole class came together to examine Figure 1a so that they could explore the concepts discussed in each group (top) as well as the concepts discussed in the transcript of the video they watched (bottom). The purpose of this discussion was to reflect on the similarities and differences between each group in search for possible connections and overarching themes about photosynthesis.

a) b)

Figure 1. a) KF word clouds of student discourse (top) and expert discourse (bottom) about photosynthesis and b) student-generated word cloud after metadiscourse session.

While students shared their observations and new insights, Thelma annotated Figure 1a. Important keywords identified by students are circled in blue and new connections made are written in black. The rise above explanation (in green) that came out of their metadiscourse is that "plants are like machines that make oxygen" and "oxygen goes in and out of plants through the stomata in the leaves". To synthesize their new understanding, students worked in small groups of three or four to draw their own word clouds. During this time, some students decided to rewatch the video and revisit their old notes to go deeper with their ideas. In Figure 1a, it can be seen that the KF word clouds of the half-groups included key concepts, such as "photosynthesis", "plant", "sun", "water", "leaf", and "stomata". In Figure 1b, however, it can be seen that a student-generated word cloud after the metadiscourse session had a richer vocabulary than the two automated word clouds combined. The students in this small group included expert concepts such as "glucose", "oxygen", "carbon dioxide", "chloroplast", and "energy", but also added new ideas, such as "molecules", "layers", "tubers", "flowering", and "rotting". A more in-depth analysis of how their vocabulary evolved over the course of their Knowledge Building is reported in Ma and Akyea (2019).

Although it has been previously established that Knowledge Forum supports the literacy development of young students, including vocabulary growth (Sun & Zhang, 2010; Chen et al., 2015), written composition (Lin et

al., 2018), and reading comprehension (Hong et al., 2020). Thelma's design iteration furthers this line of research by building directly on Resendes and colleagues' (2015) work with comparative word clouds. That is, not only can teacher-facilitated metadiscourse support the development of vocabulary growth and conceptual understanding, but students can also play a more active role during metadiscourse by identifying key concepts in their discourse and creating their own visualizations to assess the state of their community knowledge.

Design 2: Metadiscourse in Grade 6 Social Studies

In the second design iteration, Darlene facilitated a metadiscourse session with her grade 6 class (n = 18) using various analytic tools in Knowledge Forum. After studying humanitarian crises using the inquiry process for a few months, students had written notes about world health, human rights, child labour, plastic pollution, climate change, and natural disaster relief. Students also had the opportunity to connect with another class on Knowledge Forum to explore how charitable organizations like Red Cross operate in different countries. As their discussions progressed, their Knowledge Forum views became full of notes and build-on threads – some students felt overwhelmed navigating the messy views while other students felt stuck with their ideas. Darlene was concerned that if discussions continued to slow down, student interest and engagement would decline.

To address this emergent problem, Darlene worked with a researcher to design a metadiscourse session to sustain collective knowledge advancement. The purpose of this session was to experiment with different analytic tools and help students revisualize their discourse and reconsider their ideas from different perspectives. Figure 2 (top) shows a portion of the Knowledge Forum view about natural disaster relief which had over 100 notes. Because students were discussing how Red Cross responds to disaster relief in Canada and Mexico, the words "red" and "cross" were used 186 times in that view and the automated word cloud was dominated by those two words. Therefore, the lexical analysis tool was chosen in place of the word cloud tool for the metadiscourse session.

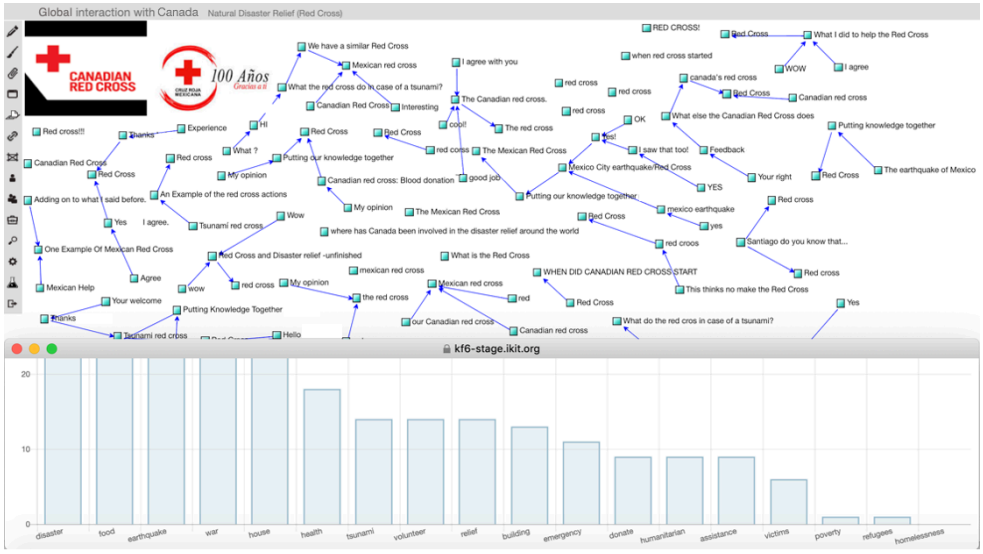


Figure 2. A Knowledge Forum view about natural disaster relief (top) with the lexical analysis tool displaying corresponding keywords (bottom) identified by students during metadiscourse session.

After reflecting on what they had learned in the natural disaster relief view, students identified a set of key concepts that they considered were critical for understanding the mission and work of the Red Cross, which included (but were not limited to): "disaster relief", "emergency assistance", "humanitarian", "earthquake", "tsunami", "victims", "refugees", "war", "food", "health", "house", "poverty", and "homelessness". Students had strong intuitions as to what the important words would be, and they gave complex interpretations as to why some words were used more frequently than others. For example, "earthquake" was one of the most commonly discussed natural disasters for relief aid because earthquakes occurred frequently in Mexico and that provided an authentic context for students in Mexico to share their ideas and experiences. "Food" and "housing" were other commonly discussed concepts because they were issues at the intersect of various humanitarian crises, including victims of natural disasters and victims of war. One key concept identified by students was "homelessness", however, it was not mentioned in the view. When students noticed this gap in their discourse, they were excited to introduce this new idea to expand discussions about housing by exploring how local and international initiatives could work together to solve the problem of homelessness. Students came to realize that one way to make new advances, is to search for

more unique words rather than the popular words. As one student put it, “If you need ideas, this tool helps you see what is and isn’t talked about”.

Next, the students reflected on their community dynamics using the social network analysis tool, the activity dashboard, the scaffold tool, and the time machine tool. Because these tools were in beta form, students were asked to make judgements as to whether the analytic tools accurately reflected their shared experiences on Knowledge Forum. One of the students’ favourite tools was the social network analysis tool. Students were excited to play with the interactive network visualizations and fondly named it the “blob”. As each student explored their position in the class network, they were honest about whom they were building onto and not afraid to openly and respectfully discuss why they were not contributing in certain areas. Through this discussion, they developed a nuanced understanding of how to interpret sociograms: To be better connected to the community, you needed to both read more and write more. That is, a balanced build-on ratio (as indicated by the various colours in the network) was a more ideal contribution pattern than becoming the largest node with the most connections. In the words of one student, “The blob helps you be a better contributor”.

With this new insight, students explored the activity dashboard, which showed the proportion of their reading, writing, and revising behaviours for each student and the class as a whole. Students could easily read the pie graphs and infer what they needed to do to be a better contributor to the community. At this point, a student raised a concern about the activity dashboard. He wondered whether this analytic tool considered the length of a note by counting the number of words in the notes because a good contributor can also be someone who writes fewer but longer notes. Students agreed that there were multiple ways to be a “good contributor” to the community and that both quantitative and qualitative analyses would be needed to inform this type of assessment.

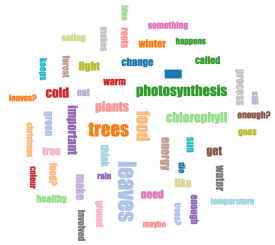
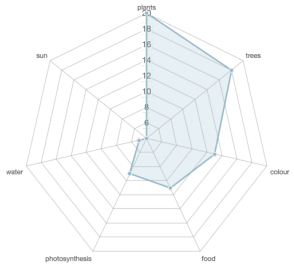
The scaffold growth tool served as another way to examine their contribution patterns. Students appreciated having a variety of “sentence starters” as entry points into their discussions but noted that they had a tendency to use some more frequently than others. For example, while “My theory” and “New information” were easier to use, “A better theory” and “Putting our knowledge together” were more difficult to use. Based on this reflection, a student suggested revising the scaffolds to encourage more diverse contributions in their discussions. Together, they designed the new scaffolds: “I agree/disagree because”, “A new theory could be”, “Putting our knowledge together, I now understand”, and “A better understanding”.

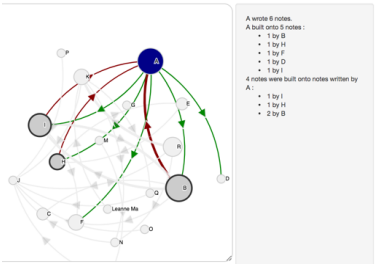
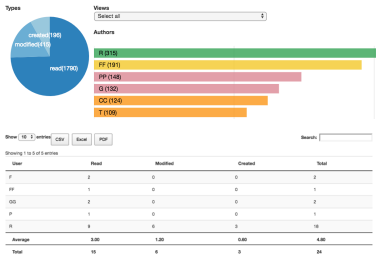
Finally, the students explored the time machine tool. This tool was another class favourite which one student coined as the “video surveillance” for their community. In addition to using the dynamic playback visualization to assess community knowledge growth where build-ons grew, students devised a strategy to use this tool to see when new questions were entered and where certain questions were not answered (i.e., no build-ons). In doing so, they could monitor their ongoing learning and find where they needed to contribute more ideas. The students’ metadiscourse inspired Darlene to envision a new analytic tool wherein keywords could be visualized as an interactive line graph to see when certain keywords emerged and how their frequency changed over time.

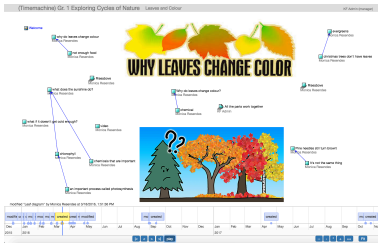
In summary, Darlene and her students found that the analytic tools transformed the way they engaged in formative assessment. Each student was able to find a different analytic tool to see where they could improve upon and support their learning forward. At times, the activity dashboard triggered some healthy competition, however, students remained thoughtful and supportive in their contributions as they were engaged in topics that were personally meaningful to them. Similar to Thelma, Darlene facilitated the metadiscourse session in a way that supported student agency and engagement. In addition to encouraging students to identify key concepts in their discourse, it was the students themselves who identified gaps in their community knowledge, found promising areas that could be expanded into new pursuits, and planned next steps to advance their community knowledge. It is interesting to note that although Darlene did not use the promising ideas tool (Chen et al., 2015) or Idea Thread Mapper (Tao & Zhang, 2018), her students engaged in similar reflection processes. Moreover, her students’ reflections around the different visualizations enabled them to take ownership over their Knowledge Building in a broader sense: After critically examining the state of their community knowledge, they deconstructed and reconstructed their interaction dynamics and discourse moves in order to operate more powerfully as a community. Table 1 (column 3) provides a further elaboration of student reflections around the Knowledge Forum analytic tools.

Table 1: Overview of KF Analytic tools from researchers, teachers, and students.

RESEARCHERS	TEACHERS	STUDENTS
WORD CLOUD		

This tool shows the big ideas in the student discourse.  **Reflection questions:** - What are the big ideas everyone is talking about? - What ideas are missing?	Knowledge Building starts with real ideas and is sustained through idea diversity. The Word Cloud tool can help you assess whether students are engaging with big ideas in the curriculum and using key terms in their online discourse. Asking students to reflect on the vocabulary makeup of their discussions can bring to light both what concepts are popular and what ideas are missing and/or neglected in their work.	The word cloud is a cloud of the most used words of the topic/ conversation. It basically gathers all the words you use in the topic and puts them inside. Big words are used most, and the smaller words are used less.
SCAFFOLD GROWTH		
This tool shows the types of contributions in the student discourse.  **Reflection questions:** - What types of contributions are needed to move our community knowledge forward?	The more diverse the kinds of ideas and the kinds of contributions in the student discourse, the more likely knowledge advancement is happening. The Scaffold Growth tool helps you visualize the types of contribution and engagement patterns in Knowledge Forum. Exploring the graph with students can inspire reflective conversations about the state of the community's knowledge at a given time.	Scaffold Growth shows the most frequent sentence starters that we use in a certain community. Some ways we're able to visualize is to see which exact contributions use each sentence starters. The most common way is the bar chart, which is a chart with each scaffold. The other way is the radar chart, which is a radar looking chart that has a number line going horizontally.
LEXICAL ANALYSIS		
This tool shows the growth of concepts in the community knowledge.  **Reflection questions:** - How are the big ideas in the community knowledge related to one another?	As students build on each other's ideas, the community knowledge grows in an interconnected manner. The Lexical Analysis tool helps you visualize which ideas and concepts grow together. Exploring the graph with students can inspire reflective conversations about the state of the community knowledge at a given time.	Lexical Analysis is a very useful tool where you input a name or a word, and it will be highlighted on each contribution it will also be shown on a chart how many times it has been used. We use it when we are searching for other people's contributions, so it's easier to find the contributions. There is also a bar chart showing which words are used the most which is very helpful for expanding our vocabulary and not using the same word repeatedly.

<table>
<tr><th colspan="3">IDEAS BUILDING</th></tr>
<tr>
<td>This tool shows the patterns of collaboration in the community.
 
Reflection questions:
- Who is reading/building on whom? Why or why not?
- How can we get all members of our community engaged?</td>
<td>Community building and Knowledge Building emerge in parallel. The Ideas Building tool helps you assess how your class is forming as a community. At a glance, you can see the degree of connectedness at the group-level. When you click on a student, you can see the build-on relation between that student and others in the community. Asking students to reflect on their collaboration patterns helps foster a sense of collective responsibility.</td>
<td>Ideas Building is a very interesting tool. This tool can show you all your connections to other students' contributions. When you open this analytical tool, you will see multiple circles with names on them, with lines connecting other circles. The more students that make contributions, the more circles you'll see, and it will be crowded with connections. The bigger an author's circle, the more connections they have with other people. We sometimes use this tool to reflect if we need to contribute more or build on to people more, showing more collaboration among students.</td>
</tr>
<tr><th colspan="3">ACTIVITY DASHBOARD</th></tr>
<tr>
<td>This tool shows an overview of basic KF activities
 
Reflection questions:
- How am I participating and contributing relative to other community members?</td>
<td>Knowledge Building is pervasive, and students often continue working on their ideas outside of school hours. The Activity Dashboard tool gives an overview of basic KF activities, such as the group totals and group averages of reading, writing, and editing behaviours. It also shows you the distribution of contributions by author. In other words, it can help you gage whether or not students are taking initiative based on how active they are relative to the group as a whole.</td>
<td>Activity Dashboard is a useful tool for many reasons. It gives an overview of the basic KF activities, such as the number of contributions you have made, read, and modified. It also shows whether the students are contributing enough to the group overall, like how much you have read, contributed, and modified over time. The visualizer is good because you can see what you have done good on and what you can work on for the future. The cool thing about the visualizer is that you can see what you have improved on and how much the class has grown.</td>
</tr>
<tr><th colspan="3">TIME MACHINE</th></tr>
</table>

This tool shows the growth of community knowledge over time.  **Reflection questions:** - How have our ideas evolved? - Are there still ideas that need our help to grow?	Continual idea improvement is the central driving force of Knowledge Building. The Time Machine tool shows the development of student thinking and the evolution of community knowledge in a given KF view. You can stop, rewind, or fast-forward through the animation to hone in on different points of the view development. Exploring the history of the view with students can help them develop a rise above perspective on their community knowledge.	The time machine is an analytical tool that shows how a view evolves and how our thinking develops from when this view was created to the present time. It can provide many uses like knowing when you made certain contributions or seeing how long someone has been waiting for a response to a question. An idea to add to make this tool even better could be for everyone to be able to slow down how fast it evolves, so you can read it easier and see all the contributions that were added, including all the connections and progress among students.

Design 3: Cross-Community Engagement in Metadiscourse

In the third design iteration, Thelma's and Darlene's students engaged in a metadiscourse session using various analytic tools in Knowledge Forum at the 2019 Knowledge Building Summer Institute held in conjunction with the Annual Meeting of the American Educational Research Association in Toronto, Canada. First the grade 6 students taught the grade 3 students how to use the analytic tools, then they used the analytic tools to explore the evolution of ideas in each other's KF communities. Students were excited to hear about each others' work and see how different features of Knowledge Forum were being used in different contexts. For example, the grade 6 students were impressed by the grade 3 students' ease of use of the drawing tool to express their ideas as diagrams and graphs and learned that notes and drawings could be integrated into rise aboves to synthesize ideas.

Even though the grade 6 students were studying social studies and the grade 3 students were studying science, their metadiscourse eventually brought them to a point of conceptual convergence. As the grade 3 students explained their Knowledge Building journey from studying oxygen in plants to carbon absorption on earth, they honed in on a few questions they were grappling with, such as why certain countries had more carbon absorption than others, and what would happen on earth if there was too much or too little carbon absorption. This sparked a lively discussion about socioscientific issues, such as climate change, deforestation, and pollution, to which one grade 6 student asked, "Is there anything we can do to help carbon absorption?". This question became another line of investigation for the grade 3 students afterward.

Similar to the grade 6 students, the grade 3 students were very fond of the social network analysis and time machine tools. The grade 3 students liked how the time machine tool could be used to see when the view was reorganized to reflect new advances and to revisit past versions to retrieve lost or deleted notes. One student suggested that the tool could be improved by helping them flag redundant or inappropriate comments. Like the grade 6 students, the grade 3 students had a common tendency to use the scaffold "My theory". The grade 3 students noted that the scaffold growth tool could help them contribute to the community in different ways, such as selecting a less frequently used scaffold like "I'd like to add on". However, another grade 3 student pointed out that newer scaffolds would have a lower cumulative number, so the graph would need to be adjusted accordingly.

Altogether, both groups of students benefited from the metadiscourse session. Darlene's students continued using the analytic tools to engage in metadiscourse in other subject areas including English class which supported rise above analyses of emergent themes across the different texts they were reading. Thelma's students continued using the analytic tools in small groups for the remainder of the school year. Metadiscourse became so pervasive in their daily classroom practices, that some students even suggested importing the visualizations as images or notes in Knowledge Forum so that they could be built on further.

Discussion

In this paper, we explored three design iterations of metadiscourse with primary-age students. In Thelma's design iteration with her grade 3 students, she extended past designs of comparing automated word clouds of student and expert discourse to include more open-ended, student-generated word clouds. In Darlene's design iteration with her grade 6 students, she used the lexical analysis tool to revisualize their discourse in ways that helped them determine

important and promising ideas that needed further work. Through metadiscourse supported by analytic tools in Knowledge Forum, both Thelma and Darlene empowered their students to explore new forms of engagement to sustain community knowledge advancement. One major finding coming from the third design iteration is that students as young as 8 and 11 years of age can offer sophisticated interpretations of their online activities with the Knowledge Forum analytic tools. Not only were they open to novel forms of data visualization, such as sociograms and radar charts, they were aware of the potential limitations of these data visualizations and offered insightful reflections for our engineers. Some of the concerns they have raised are currently being debated by experts in the field of learning analytics and educational technology (Selwyn, 2019). Our research team is now incorporating teachers' and students' recommendations in the next design iteration of the Knowledge Forum analytic tools. For example, engineers are creating new tools to transform word count into measures of lexical richness and conceptual diversity. The word cloud tool is also being integrated with the lexical analysis tool to allow for filtering of keywords and multiple visualizations in the form of bar, radar, and line graphs (see for example Ma, 2018).

Another major takeaway from this work is that through continued use of Knowledge Forum, students became designers in every possible way. Students treated the analytic tools as conceptual artifacts (i.e., objects to think with) and found enjoyment in experimenting with new strategies and tinkering around with new tools as learning scientists and engineers would do. By adopting an "improvable ideas" mindset, they were quick to offer creative ways to use those tools to support their learning. We find it fascinating how their metadiscourse sessions about improving their community knowledge and community dynamics evolved into design sessions for improving assessment tools to provide feedback for their community – past research has identified the role of metadiscourse in helping students revise their knowledge goals but not necessarily refine their assessment methods (e.g., Chen et al., 2015; Tao & Zhang, 2018). Of course, we are not suggesting that every metadiscourse session should unfold in such a manner, and we are well aware of the potential risk of reinforcing performativity in schools when too much value is given to prescriptive assessments derived from superficially-constructed quantitative measures. We do maintain, however, that discourse and metadiscourse are critical for advancing students', as well as our Knowledge Building. For this reason, we propose that if students are truly to assume higher levels of agency for creative knowledge work, they ought to play some role in helping us design tools and environments optimized for knowledge creation.

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