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Group-level formative feedback and metadiscourse: Effects on productive vocabulary and scientific knowledge advances in grade 2

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Abstract This research explores the ability of grade 2 students to engage in productive discussion about the state of their knowledge building using group-level feedback tools to support their metadiscourse. Two aspects of knowledge work were common to the comparison and experimental classes: "Knowledge Building talk" (KB talk) involving teacher-student discussions and the use of Knowledge Forum, an online environment optimized to support Knowledge Building/knowledge creation and to represent and support student work and KB talk. Students in experimental conditions additionally reviewed visualizations of vocabulary use and discourse patterns during KB talk time. Two formative feedback visualization tools were co-developed by the classroom teacher and researchers to show (a) overlaps and discrepancies between words students used in their Knowledge Forum notes and words used by writers more knowledgeable in the field and (b) frequency of discourse moves indicated by students' use of epistemic discourse markers in Knowledge Forum. These visualizations served as grounding for KB talk concerned with interpreting the visualizations and considering their implications. A comparison of two classes similar except for presence or absence of these visualizations showed significant effects favoring the experimental class in domain-specific vocabulary, scientific understanding, epistemic complexity of ideas, and interpersonal connectedness of online discourse.

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Introduction

In their analysis of exemplary constructivist approaches in education, Bielaczyc and Collins (1999) observed that public discussion "is one of the central ways that a learning community expands its knowledge" (p. 283). This is particularly true in Knowledge Building,[1] with its emphasis on students taking responsibility for continual idea improvement (Scardamalia and Bereiter 2006; van Aalst 2009). The importance of constructive dialogue is also well recognized in organizational knowledge creation (Tsoukas 2009; von Krogh et al. 2000), which is conceptually the same as Knowledge Building (Bereiter and Scardamalia 2014).

A crucial issue in collaborative knowledge-building/knowledge-creating discourse is whether the dialogue is making progress toward a knowledge objective (Bereiter et al. 1997). If students are to take on the central role in knowledge building, they need to evaluate their group's knowledge progress, recognize trouble spots, and alter their discursive practices to improve results. This means students need to carry on productive "metadiscourse." The term is used here in its philosophical sense, as "discourse about the discourse" (cf. Simmons 1993, pp. 92–93). (There is a more restrictive use of the term in linguistics, where metadiscourse refers to parts of a sentence that afford a perspective on the sentence itself—for instance, the phrase "in conclusion"). Synonyms for metadiscourse include "metacommunication" (Baltzersen 2013) and "metatalk" (Stromer-Galley 2007). The general concept covers a wide range of "meta" issues, but in the context of educational discussion, the key function of metadiscourse is for students to "reflect on their own and on the community's progress in understanding" (Bielaczyc and Collins 1999, p. 284): Are we addressing our problems of understanding? Are we making progress on our theories? Are we getting stuck? How can we move forward? Metadiscourse thus entails formative evaluation aimed at group-level assessment of progress and at helping guide future action.

Metadiscourse presupposes an ability to take a detached perspective and view the discourse itself as an object of inquiry. This raises the question, therefore, of whether young students are capable of doing it and, further, the design question of what kinds of supports might enable them to do it. Those questions motivated the present study. Metadiscourse would seem to require cognitive development at the level of what Inhelder and Piaget (1958) called "formal operations," and which they characterized as an ability to carry out "operations on propositions." This ability was not thought to emerge fully before adolescence. However, the educational approach known as Knowledge Building (Scardamalia and Bereiter 2006, 2014), which has been practiced at all levels from kindergarten on up, seems to defy this limitation. In the present study, metadiscourse was examined in grade 2 children (approximately 7 year olds).

Knowledge Building has been defined in its most general sense as "productive work that advances the frontiers of knowledge as these are perceived by a community" (Bereiter and Scardamalia 2003, p. 1370). Thus, it is conceptually identical to "knowledge creation" as

[1] Because the term "knowledge building" now appears in many documents, often without definition, we use lower case with the generic term and capitalize Knowledge Building when referring to the approach originating in our laboratory and promoted by organizations such as Knowledge Building International.

practiced in knowledge-creating organizations (Nonaka and Takeuchi 1995; Paavola and Hakkarainen 2005), which raises further questions about whether children have the requisite capabilities (Bereiter and Scardamalia 2014). A common feature of Knowledge Building pedagogy at all levels is an activity that Reeve et al. (2008) call "KB talk." This is whole-group discussion in which students freely bring up whatever questions, ideas, insights, and problems they have in relation to their knowledge-building efforts, with the teacher providing support as needed to foster knowledge-building discourse. This typically involves reflection on the current state of an inquiry, which is certainly metacognitive, but which may or may not include metadiscourse, depending on whether there is reflection on the knowledge-building discourse itself. Metadiscourse of some kind is a normal element in KB talk; the present study represents an experimental approach to enhance it through formative feedback.

Formative feedback in collaborative knowledge building

"Formative feedback," as the term is used in this study, refers to any kind of information derived from ongoing group knowledge-building activity that can be used by the group to further its knowledge-building efforts. This is consistent with but represents a particular focus on formative evaluation, which has been defined as "the use of systematic evaluation in the process of curriculum construction, teaching and learning for the purpose of improving any of these. . ." (Bloom et al. 1971, p. 118). It has typically focused on individual performance data and its aggregation into group means. Social network analysis represents one of the earliest breaks from this individualistic focus, since it deals with interpersonal connections and overall patterns of such connections (Freeman 2006; Wasserman and Faust 1994). Referring to the focus of the present study as "formative feedback" rather than "formative evaluation" adds a further constraint. As Ramaprasad (1983) pointed out, information only constitutes feedback if it has an effect on behavior. Accordingly, the present study devised and tested forms of group-level feedback, examining both students' direct response to the feedback and its effect on the quality of their knowledge-building discourse. In the present study, we experimented with two forms of group-level feedback designed for classroom use: feedback about the group's use of domain vocabulary and feedback about types of contributions to knowledge-building discourse. Effects on students' interaction patterns, use of new vocabulary, and advances in scientific understanding were examined. In addition, a new kind of semantically based social network analysis—Knowledge Building Discourse Explorer (KBDeX; Matsuzawa et al. 2011; Oshima et al. 2012) was used to examine patterns of socio-cognitive interaction.

Productive vocabulary and discourse moves to advance knowledge building

Vocabulary knowledge plays a major role in educational attainment (Snow et al. 2007; Stahl and Fairbanks 1986). In Knowledge Building and in constructivist educational approaches more generally, *productive* vocabulary takes on special significance. This is vocabulary actually used by students in speaking and writing, as distinguished from what is usually a larger *receptive* vocabulary, consisting of words students recognize and understand but do not necessarily use in their speech and writing. For obvious reasons it is easier to test receptive vocabulary than productive vocabulary, and so most of the research on vocabulary learning deals with it. While there are well-researched ways of teaching receptive vocabulary (Beck et al. 1987), advancing productive vocabulary appears to be a less developed area of pedagogy, except in second language instruction (Nation 2001). In knowledge building it is not enough that students incorporate new words into their speech and writing, they need to incorporate new word meanings into their thinking and their contributions to collective knowledge-building discourse. Breadth of vocabulary facilitates learning, with increases in domain knowledge serving to further broaden vocabulary and deepen comprehension (Cobb et al. 2003; Hirsch 2003).

Discourse moves play a similarly critical role in knowledge building. Chan (2001) distinguished between surface moves such as ignoring or rating information and problem-centred moves requiring formulation of questions and explanations. Successful learners use significantly more problem-centered moves. Similarly, Zhang et al. (2007) identify moves within a discursive community, leading to productive interactions that contribute to the "scientificness" (defined below) of the discourse. These moves include "I disagree, because…"; "What's your evidence?"; and "Can you think of a way to test your theory?" Chuy et al. (2010) found evidence that theory-development scaffolds used in Knowledge Forum (e.g., "My theory," "Our improved theory") resulted in deeper understanding of the role of ideas in scientific inquiry and in theoretical progress. Analyses of conceptual, epistemological, and socio-cognitive processes associated with quality of discourse are shifting from a focus on individual communicative behavior to community interchanges, connected discourse, and collective cognition (Chan 2013; Puntambekar et al. 2011). Bereiter (2010) stresses the importance of meta-dialogue with focus on the overall effect of connected discourse as signified in discourse moves and questions such as "Are we getting anywhere?" "What is the state of the art and how does our work stack up against that standard?" and "How might we reorganize ourselves to make greater progress?"

In the present study discussing the meaning and use of new domain vocabulary in building knowledge and the presence or absence of discourse moves related to theory development were treated as important subjects of metadiscourse. New tools were developed to help students assume a higher level of agency in such metadiscourse.

Research questions

In summary, the present study was concerned with the design of tools to provide feedback in the form of group-level visualizations of collective knowledge building, with the goal of promoting metadiscourse and, in turn, productive vocabulary and conceptual development. This led to the following research questions:

(1) Can young students (approximately 7 years old) carry on productive metadiscourse?
(2) What kinds of pedagogical support and feedback regarding group knowledge building are effective in promoting metadiscourse at this age level?
(3) How does formative feedback affect the quality and connectedness of students' knowledge building discourse?
(4) Does metadiscourse improve vocabulary development and conceptual understanding?

Participants, classroom context, and knowledge building practices

An experiment to answer these questions used a time-lag design in which a grade 2 class taught by one teacher served as the comparison class and the grade 2 class taught by the same teacher the next year served as the experimental class. The comparison comprised 21 students: 11 boys and 10 girls. The experimental class also comprised 21 students: 10 boys and 11 girls. These students attended a school that typically engages students in knowledge-building practices from kindergarten, and uses Knowledge Forum from grade 1. The school is a laboratory school at the University of Toronto, with a culturally and economically diverse student body; at present approximately 40 % of the students are self-identified as visible minorities, 10 % receive financial assistance and 15 % receive special-education support. Knowledge-building discourse is carried out through a blending of online work in Knowledge Forum and face-to-face group discussion, called KB talk (Reeve et al. 2008). Thus, all students had experience with the pedagogy and technology upon entering grade 2. Both the experimental and comparison classes undertook the same two knowledge-building units. These units corresponded to the Ontario curriculum's "Understanding Life Cycles" science strand for grade 2, specifically the "Growth and Change in Animals" inquiry stream (Ontario Curriculum Standards 2007, p. 59). In both classes, students began with a knowledge-building study of approximately 4 months' duration on birds, and moved on to do another 4-month investigation on salmon.

Because the number of computers in each grade 2 class was eight, the students were split into two groups that rotated through sessions they referred to as "KB time." Half of the students left the classroom to go to the library while the other half engaged in KB talk and Knowledge Forum work. The rotation groups were chosen by the teacher, who selected the same number of boys and girls for each group and chose students she believed represented a mix of abilities and achievement levels. These rotation groups persisted throughout the school year. Although their knowledge-building sessions occurred on different days, students worked in the same Knowledge Forum database, thus giving every student access to ideas arising in both rotation groups. For each rotation group, KB talk and Knowledge Forum work typically consisted of one 45–60 min session a week. In the comparison class, KB talk had the wide-ranging, teacher-facilitated, student-driven character described previously. This was true in the experimental class as well. However, eight of the sessions included experimental interventions to be described. After discussion, students were given 20 to 30 min to enter their ideas into Knowledge Forum.

Knowledge Forum provides support for what Brown and Campione (1996) called a "metacognitive view" of students' work. Graphical layouts of note icons and connecting links provide a view of the growing hypertext. Notes are moveable, permitting arrangement of notes against background diagrams or pictures that provide context and lend structure to the note array. Scaffolds provide easy means for students to identify discourse moves: "My theory," "New information," and so on. These affordances are more fully described in Scardamalia and Bereiter 2006. Knowledge Forum was used in all conditions, so it is not treated as a variable in the present research. Instead, the research tested interventions intended to more directly promote knowledge-building metadiscourse.

Both classes had approximately the same amount of KB time throughout the year. Students were typically assigned two to each computer and took turns making contributions to the database when it was time to write on Knowledge Forum. In addition to 45 to 60 min of conversation and online "KB time," students engaged in active research to increase their knowledge of birds and salmon. They took nature walks during which they made and recorded observations about birds in the neighborhood, examined objects such as owl pellets, feathers, and nests, and dissected fish in the classroom. They also participated in the "Classroom Hatchery" component of the Lake Ontario Salmon Restoration Program (see www.bringbackthesalmon.ca), in which students raise

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salmon in their classrooms and then release them into the wild. Thus, students in both the comparison and experimental classes had a rich experiential environment in which to carry on their knowledge-building work.

Experimental intervention to enrich knowledge building metadiscourse

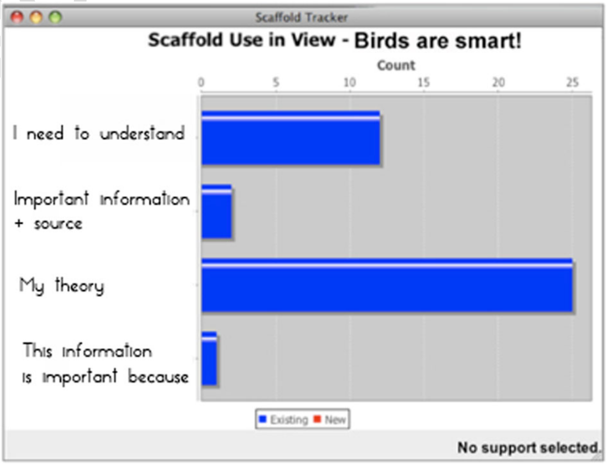
Experimental interventions, the effects of which are the subject of the present study, were introduced in the regularly scheduled KB talk and Knowledge Forum sessions described above. These consisted of entering into KB talk information provided by (1) a vocabulary assessment tool, using word clouds and (2) an epistemic-discourse-moves tool, graphing the extent of use of different Knowledge Forum scaffolds. As the results generated by these tools changed from one session to the next, they provided new information for students to reflect on in each session. The intent with both of the tools was to show students information readily comprehensible to them and with clear relevance to their knowledge building, but that they could not acquire through their regular work in Knowledge Forum.

(1) *Comparative Word Clouds*. Word clouds are representations of vocabulary usage in texts, with visual properties such as font size, color, position, or boldness used to indicate frequency of use or some other variable of interest (Bateman et al. 2008). Typically, the more a word is used in the source text, the larger it appears in the cloud. Word clouds have been shown to be educationally beneficial in a number of ways. For example, word clouds can summarize content in a helpful manner (Schrammel et al. 2009), signal individual or social interactions in a dialogue, act as "suggestive device[s]" for underlying phenomena in source data (Xexéo et al. 2009), and illuminate implicit or hidden relationships in unstructured data (Koutrika et al. 2009). To serve purposes of formative assessment in this study, the Comparative Word Clouds visualization presented three different word clouds side-by-side, as shown in Fig. 1: (a) "Our Words," a cloud based on word frequencies in Knowledge Forum notes on the current theme; (b) "Expert Words," based on authoritative source material on the same theme; and (c) "Our Shared Words," words in student entries that also appeared in the "Expert Words" cloud. The "Our Shared Words" cloud showed words common to both texts by reproducing the "Expert Words" cloud with a colored font used to identify words that also appeared in the students' texts. (In the version of the tool used in this study, the color-coding was done manually, using Adobe Photoshop. In future versions, this can be done automatically). Word clouds generated on successive occasions might show increasing diversity in vocabulary or converge on a few key words, the uptake of "expert" words into the students' discourse, or continued discrepancy between student and "expert" vocabulary—thus, a variety of results to fuel knowledge-building metadiscourse.

2) *Epistemic Discourse Moves Tool.* This tool was designed to help students take a meta-level perspective on their knowledge-building discourse. As shown in Fig. 2, the tool produces easy-to-read bar charts that depict the frequency of use of each kind of scaffold in a specific Knowledge Forum view. This type of feedback allows students to monitor the types of discursive moves that are being made—or that are found to be lacking—in their collective discourse at any given time. Use of this tool complements the word clouds by helping students gain an overall picture of their collective epistemic activity. The graph in Fig. 2 might, for instance, lead students to question whether it was good to have so many

Fig. 1 Visualization facilitating metadiscourse: Word Clouds based on terms emerging from students' own dialogue and expert words from authoritative source material

ideas (using the "My theory" and "I need to understand" scaffolds) accompanied by so little new information. Reflection on this bar graph was intended to help students decide when it might be fruitful to engage external sources or design experiments to help them develop their ideas. At the same time, having access to content-oriented feedback such as the word clouds gives students the opportunity to encounter unknown terms and concepts



Q7 **Fig. 2** Visualization facilitating metadiscourse: Bar graphs produced by the Epistemic Discourse Moves tool showing frequency of use of Knowledge Forum scaffolds "I need to understand," "Important information + source," "My theory," and "This information is important because."

in an authentic context of inquiry, and try to apply these terms to their own ideas, or use them as entryways to guide new directions for research and information-seeking.

The role of the teacher

KB talk is normally student driven, with the teacher providing guidance and encouragement only as needed to help the students take collective responsibility for advancing their ideas. Students are expected to report discoveries, identify problems of understanding, reflect on progress, determine next steps, and so forth. The teacher models such kinds of engagement and helps advance the conversation as needed, asking students to further elaborate and explain their thinking, consider problem areas they may have missed, think about next steps, and so on. Thus, normal KB talk includes metadiscourse of varying kinds and quantity. From the standpoint of the teacher's role, the change brought about by the experimental interventions consisted of introducing formative feedback information into the KB talk sessions within the context of knowledge-building efforts. As the teacher explained the difference in an interview,

> Typically, … KB talks focus on developing and discussing theories, posing questions, and bringing new information to the group. The talk around the graphs and word clouds added a new focus: that of helping children be aware of the quantity and type of notes they wrote in the view. Through discussions of this sort, children saw how those notes often affected the direction of their learning.

Procedure

Throughout the school year following the year in which she taught the comparison class, the teacher and the first author engaged in an intensive process of co-design (Roschelle et al. 2006) to plan the experimental interventions described above. They met approximately twice a month for 30-min conferences during the regular school year, with other researchers being involved more incidentally.

In both the comparison and experimental classes, students participated in two consecutive knowledge-building units that lasted approximately 16 weeks each. In the experimental class, the eight sessions that incorporated formative feedback tools were woven into the existing knowledge building practice; they did not constitute additional sessions. The intervals between these sessions were not always equal because of scheduling of a class play, holidays, and so forth.

Within the experimental class there were two distinct student groups: Experimental Group A, and Experimental Group B. These two groups comprised the knowledge-building rotation groups selected by the teacher, as described above. The two groups differed in the kinds of formative feedback they received. Experimental Group A received and discussed results obtained with the Comparative Word Clouds tool. Experimental Group B received and discussed results from both the Comparative Word Clouds tool and the Epistemic Discourse Moves tool. Thus the design permitted limited testing of differential effects of the two tools but did not provide for separating the effects of talk and tools—tool and talk being inextricably related in the context of KB talk. Consequently, tools and teacher-student discussion focusing on them functioned as a package.

Dataset and analyses

The dataset for the study included the following sets of Knowledge Forum notes: (a) Comparison Class: 248 notes across four views—114 notes in three views from the bird unit and 134 notes in one view from the salmon unit; (b) Experimental Class: 203 notes across eight views—175 notes in seven views from the bird unit and 90 notes in one view from the salmon unit. In addition, videos of student-teacher talk about visualizations in the experimental class were examined to provide qualitative information about students' metadiscourse abilities and their response to the visualizations.

Measures used in addressing research questions

Data were analyzed to explore growth in vocabulary, the level of understanding demonstrated in student writing, and the extent to which vocabulary use was distributed in the student community. The application of behavioral, lexical, and knowledge advancement measures are summarized below, as well as the approach to analysis for group-level dynamics:

- *Behavioral measures*: The Knowledge Forum Analytic Toolkit (Burtis 1998) was used to calculate the number of notes authored per student and the percentage of notes read per student.
- *Lexical measures*: The Knowledge Forum Analytic Toolkit was also used to calculate lexical profiles for each student. Spelling errors were manually corrected so that all words could be picked up by the automated tools. Three attributes were used to create students' lexical profiles: (a) academic words—the Academic Word List (AWL) is composed of 570 root words common in academic discourse but not among the 2000 most frequently used English words. Academic words include terms such as *hypothesis, source,* and *theory*, which are found at higher-than-normal rate in academic discourse and commonly thought to correspond with higher-level knowledge work; (b) 1st 1000 words—these include the most commonly used words in the English language, such as *was, with, they, each,* plus their grammatical variations. Disproportionate use of these words is indicative of a limited vocabulary (Nation 2001); (c) domain-specific words—the Ontario Curriculum Standards document was used to identify key words found in the section on "Understanding Life Systems," which was the basis for the two knowledge-building units that students engaged in during the present study. This strand runs from grades 1–8 and becomes "Biology" in grades 9–10. In total, 342 individual domain-specific terms ranging from grades 1 to 10 were identified. These terms related to components of this curricular strand such as "Growth and Changes in Animals," "Biodiversity," "Interactions in the Environment," and "Sustainable Ecosystems." Curriculum terms were divided into two levels according to the grade in which they appeared in the curriculum documents: 84 words were identified at or below the grade 2 level, and 258 words above the grade 2 level. Examples of higher level domain-specific words are *habitat, ecosystem, criteria, feather, waste, organic, resource, function, regurgitate, mammal, navigate, interdependent, reproduce, seedling, prey, survival, predator,* and *pollute*. In addition to curriculum terms, the author and classroom teacher consulted external sources available in the classroom and identified "expert" terms relevant to particular streams of inquiry as they emerged during the course of knowledge- building work. These words appeared on the word cloud visualizations to help students expand their vocabulary. For analysis, a total of 64 "expert" words retrieved from classroom sources were combined with the 342 curriculum words to create a single comprehensive list. This cumulative list, which totaled 406 words, plus their grammatical variations,

was used to measure domain-specific vocabulary. Examples from this list include *redd, Chinook, tributary, parr, gizzard, coniferous*, and *Atlantic.*

- *Knowledge Advancement*: To examine community knowledge advancement, two researchers coded notes according to the "Ways of Contributing to Explanation-Seeking Discourse" schema, which was co-developed by several authors to aid in content analysis of knowledge- building discourse (see Chuy et al. 2011). This schema includes six main contribution types: "Asking thought-provoking questions," "Theorizing," "Introducing New information," "Working with Information," "Synthesizing and Comparing," and "Supporting Discussion." It also includes 24 subcategories that describe more specific discourse moves. For instance, subcomponents of "Theorizing" include "proposing an explanation," "supporting an explanation," "improving an explanation," and "seeking an alternative explanation." Notes coded as demonstrating "Theorizing" were further analyzed to assess depth of understanding. This analysis was guided by two coding schemas developed by Zhang and colleagues (2007) to measure "scientificness" and "epistemic complexity" of ideas. Scientificness is the degree of scientific accuracy displayed by a note, scored according to the following rubric:

  1. Prescientific (contains misconception + naive conceptual framework);
  2. Hybrid (contains misconception + some scientific information);
  3. Basically scientific (not precise, but applies scientific framework);
  4. Scientific (consistent with scientific knowledge).

  "Epistemic complexity" represents the level of cognitive effort and written sophistication evident in an explanation, scored according to the following rubric:

  1. Unelaborated facts (simple statements);
  2. Elaborated facts (elaboration on terms, phenomena, etc.);
  3. Unelaborated explanations (includes reasons, relationships or mechanisms);
  4. Elaborated explanations (elaborations on reasons, relationships or mechanisms).

  Overall, for the Comparison Class the inter-rater agreement rate was 94.95 % for scientificness and 89.94 % for epistemic complexity. For the Experimental Class, the corresponding agreement rates were 81.45 and 90.76 %.

- *Group discourse network structure*: On a group level, notes were analyzed using Knowledge Building Discourse Explorer (KBDeX) (Matsuzawa et al. 2011; Oshima et al. 2012). KBDeX was developed specifically for analysis of knowledge building discourse in Knowledge Forum, using semantically based social network analysis. In this study it was used to map network structure of discourse based on co-occurrence of specified words in unique notes; likewise, the relation between two authors (students) was indicated by co-occurrence of words in their notes. On the basis of these co-occurrence measures, KBDeX was used to gauge the extent to which vocabulary use was shared among the students, based on degree centrality (DC), betweenness centrality (BC) and closeness centrality (CC). These measures represent standard points of analysis in complex network science (Newman 2010). Degree centrality measures the "popularity" or number of connections one node has with other nodes in the network. In the student network, for example, each network node represents a student, with connections between students created through the use of the same word. So, the more discursive connections a student has with other students, the more "popular" or centralized that student is in the network. Betweenness centrality provides a measure at both a local and global level indicating the degree of connectivity of a node as well as the "load" placed on the node by all other nodes. For this research, this measure reveals the extent to which a student is connected within the community and the degree to which she bridges various social clusters or discursive cliques, respectively. Exploring the average betweenness centrality in each classes' discourse offers a glimpse into the collaborative structure operating in each class. For example, it can identify whether students are connected in a network of exclusive groups, with particular clusters of students discussing different themes with little cross-talk, or, alternatively, whether the discourse patterns are more reflective of "opportunistic collaboration" (see Zhang et al. 2009; Zhang and Messina 2010) with the whole class forming an interactive network. A higher average on this measure would suggest a more dispersed network, as opposed to a dynamic and highly collaborative one; high betweeness centrality or dispersion would decrease the likelihood of opportunistic collaboration.

Closeness centrality measures the proximity of one node to all other nodes, and is indicative of how quickly information can flow through a network. Applied to this scenario, this measure reveals how closely connected students are to each other via the discourse in which they are engaged. In the case of vocabulary, this measure helps to show possible semantic relations and connections students are making through their use of words. The domain-specific and academic words that were used by the students in each class, generated from their lexical profiles, comprised the word lists that were entered into KBDeX and provided the vocabulary markers for the program to trace. In this way, the discursive relationships between students fostered by common use of key vocabulary could be mapped.

Results

Results are presented in an order different from the order of research questions in the introduction. Frequency data describing individual behaviour, including vocabulary usage and types of online contributions, are presented first, followed by ratings of note content, and then semantic network analysis data indicating effects on classroom communication. We turn finally to the overarching question of the research, the ability of young students to make use of group-level formative feedback and carry on productive metadiscourse. Frequency, rating, and semantic network data bear indirectly on this issue; more direct evidence comes from qualitative analysis of metadiscourse, presented in a later section.

Effects on general activity in Knowledge Forum

As Table 1 indicates, there was no consistent experimental effect on general activity in Knowledge Forum. Experimental Group A students produced and read fewer notes and read a smaller percentage of notes than either the Comparison Class or Experimental Group B. Analysis of variance, however, showed none of these differences to be statistically significant ($F(2, 39)=1.7$, $p=.19$, and $F(2, 39)=1.32$, $p=.28$, respectively).

Effects on vocabulary usage

One-way analyses of variance showed intergroup differences significant at the .05 level on all the lexical measures reported in Table 2 except for number of academic words, which was very

Table 1 Behavioural measures across three groups

Behavioural measures	Comparison class		Experimental group A		Experimental group B	
	M	SD	M	SD	M	SD
Number of notes written	11.43	6.72	9.64	3.01	14.00	4.22
Number of notes read	43.95	30.34	29.55	13.97	38.60	13.99
% of notes read	17.72	12.23	12.80	7.91	15.26	5.53

low in all groups, and percentage of words on the 1000 most frequently used words list, which amounted to about two-thirds of the words used in every group. Number of words written mirrored the profile of number of notes written, with students in Experimental Group A writing the fewest words. Post-hoc tests based on *Tukey's HSD* show that Experimental Group B wrote significantly more words than Experimental Group A ($p<.05$, Cohen's $d=70.01$), but not significantly more than the Comparison Class. Turning to the use of domain vocabulary, however, we see a more consistent experimental effect. As shown in Fig. 3, Experimental Groups A and B surpassed the Comparison Class in number of domain words used, number of unique domain words, and percentage of domain words above grade level. Planned comparisons between comparison and combined experimental groups showed a significant advantage for the experimental groups on all three measures ($t(39)=3.24$, $p<.01$; $t(39)=3.28$, $p<.01$; $t(39)=3.69$, $p<.001$, respectively). Experimental Group B also surpassed Experimental Group A on these measures, but this difference was significant only for total domain words ($p<.05$, Cohen's $d=6.47$), where group B also significantly surpassed the Comparison Class ($p<.01$, Cohen's $d=8.21$).

Effects on types of contributions

Because feedback provided by the Epistemic Discourse Moves tool pertained most directly to the kinds of discourse moves or types of contributions made by students, it was expected that it should have an effect on this aspect of students' knowledge-building activity. To determine if this was the case we examined types of contributions manifested in Knowledge Forum notes based on rater classifications of note content. Because of the large number of categories and subcategories, we report here only those showing a significant difference between Experimental Group B (the only group receiving feedback regarding discourse moves) and

Table 2 Lexical measures across three groups

Lexical measures	Comparison class		Experimental group A		Experimental group B	
	M	SD	M	SD	M	SD
Number of words written	123.52	69.16	109.73	62.02	188.30	86.92
Number of domain words	7.76	5.85	10.82	5.47	18.00	9.08
Number of unique domain words	5.95	4.42	8.55	3.93	12.90	5.97
% domain words above grade level	2.13	1.64	4.05	2.60	4.90	2.21
Number of academic words	0.57	0.75	0.54	0.68	0.60	0.52
% words in 1st 1000	68.53	9.02	66.53	6.92	69.06	7.35

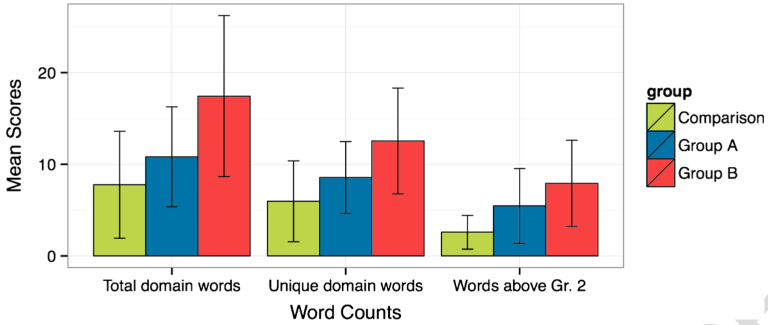


Fig. 3 Mean counts for number of domain words, unique domain words, and words above the grade 2 level

the other two groups. Group B showed a significantly higher incidence of Proposing an Explanation, Obtaining Information, and Reporting Experimental Results (the last being virtually nonexistent in the Comparison Class and Experimental Group A).

Effects on "scientificness" and epistemic complexity

figure 4 depicts the mean ratings on "scientificness" and "epistemic complexity" of Knowledge Forum notes produced by the three student groups. As described in the Data Analysis section, analyses are based only on notes that exhibited aspects of "theorizing." In the Comparison Class, all students contributed "theorizing" notes, with an average of 5.52 notes of this type out of an average of 12.62 total note contributions per student. Similarly, all students in the Experimental Class were "theorizing," contributing an average of 6 in this category out of an average of 13.32 total note contributions per student.

Results from one-way ANOVA comparisons between groups on knowledge advancement measures show significant differences for scientificness ($F(2, 38)=11.14$, $p<.001$) as well as epistemic complexity ($F(2, 38)=3.37$, $p<.05$). Post-hoc tests (*Tukey's HSD*) indicate that both Experimental Groups A and B performed better than the Comparison Group on scientificness ($p<.01$, Cohen's $d=0.59$) and epistemic complexity ($p<.05$, Cohen's $d=0.39$). There was no significant difference between Experimental Groups A and B on these measures ($M=2.61$, $SD=.67$ vs. $M=2.51$, $SD=.24$ for scientificness; $M=1.68$, $SD=.38$ vs. $M=1.72$, $SD=.49$ for

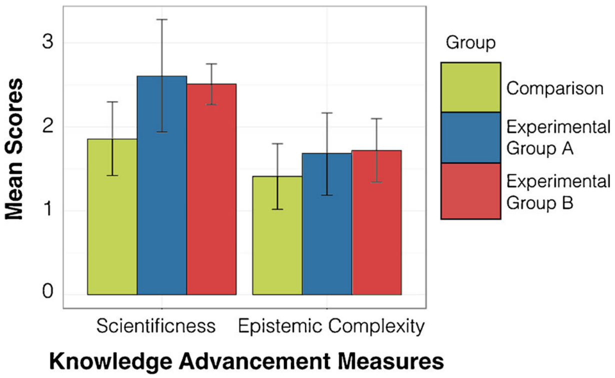


Fig. 4 Mean scores for knowledge advancement measures across three groups

epistemic complexity). Although Group B wrote significantly more words than Group A, as indicated in Table 1, this had no evident effect on their knowledge scores. Overall, findings show that group-level formative feedback and accompanying metadiscourse resulted in greater scientific accuracy and more elaborate explanations in students' subsequent online work.

Effects on communication structure

It was expected that metadiscourse supported by formative assessment tools would result not only in vocabulary and knowledge gains by individual students but also an increase in shared active vocabulary. Network structure analysis would show this as an increasingly dense and coherent structure based on the co-occurrence of significant words in the notes of pairs of students. Network structure analysis was conducted using KBDeX to explore group-level dynamics as evident in online dialogue. Although, as indicated previously, the experimental group was split into two groups receiving different interventions, both groups worked in the same Knowledge Forum database. Accordingly, no distinction is made between Experimental Groups A and B in the network analysis. Similarly, in the Comparison Class no distinction is made between the rotation groups established to manage computer use. Table 3 presents means of degree, betweenness and closeness centrality that were calculated for each class using KBDeX. The dynamics measured by these indices are visualized in Fig. 5, which reveals the social/semantic network structure of students' discourse based on shared vocabulary across comparison and experimental classes. As this graph shows, the experimental class exhibits a denser social/semantic network characterized, with connections between more members than those in the Comparison Class. From a social network perspective, higher density networks provide more paths for information or knowledge exchange thus enabling faster circulation of shared resources (see Haythornthwaite and Gruzd 2012; Haythornthwaite 2010). Although no quantitative test for density was performed here, it is apparent from Fig. 5 that the communication network was much denser in the experimental class than in the comparison class while neither class showed much evidence of formation of discursive cliques, such as may be found in classes organized around small group work (cf. Zhang et al. 2007).

To test statistical significance of differences in the social/semantic network structure of comparison and experimental classes, a series of one-way ANOVAs were conducted comparing Experimental Group A, Experimental Group B, and the Comparison Class on the degree, betweenness and closeness centrality of each group's social network. Results showed significant differences for degree centrality $F(2, 39)=10.78$, $p<.00$, betweenness centrality $F(2, 39)=12.16$, $p<.0001$, as well as closeness centrality $F(2, 39)=15.06$, $p<.0001$. Post-hoc tests (*TukeyHSD*) showed that both Experimental Groups A ($p<.01$, Cohen's $d=.16$) and B ($p<.001$, Cohen's $d=.18$) displayed greater degree centrality and closeness centrality

Table 3 Means of degree, betweenness and closeness centrality between comparison and experimental classes

	Degree centrality		Betweenness centrality		Closeness centrality	
	2011	2012	2011	2012	2011	2012
Students	0.801	0.983	0.009	0.001	0.849	0.984
Notes	0.021	0.059	0.001	0.003	0.005	0.009
Words	0.057	0.043	0.014	0.016	0.043	0.056

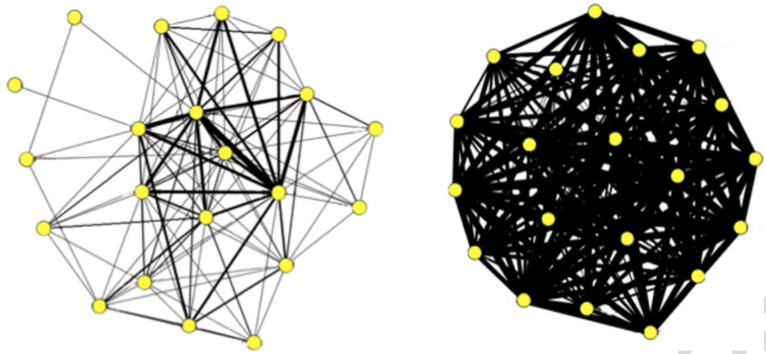


Fig. 5 Social network of students in the comparison (*left*) and experimental (*right*) classes, with *yellow dots* representing individual students and thickness of lines indicating number of shared key words

(p<.0001, Cohen's d=.1) than the Comparison Class. However, the Comparison Class showed greater betweenness centrality than both Experimental Group A (p<.001, Cohen's d=.0091) and B (p<.001, Cohen's d=.0090). These findings indicate that both Experimental Groups A and B included more students who had more connections with other students than in the comparison group. This suggests that a greater number of students in the experimental cohort were using more shared words more often and were thus more highly connected to each other in terms of shared vocabulary. Also, the fact that the comparison students exhibited a higher betweenness centrality means that in this group, students were more dispersed in terms of their use of common words, with more distinct social clusters engaging in different streams of discussion that did not necessarily include many other students. Post-hoc tests did not show significant difference between Experimental Groups A and B on any measure, their similarity being evident in Fig. 6.

Qualitative evidence of metadiscourse

Results reported in the preceding sections are consistent with what was expected from engagement in metadiscourse: advances in scientificness and complexity of discourse, increased use of domain vocabulary and discourse moves, and a more coherent communication network. However, none of these results provide direct evidence that the children actually engaged in metadiscourse. In this section we examine three kinds of discussion that took place during metadiscourse sessions and that more directly exhibit children's ability to carry on

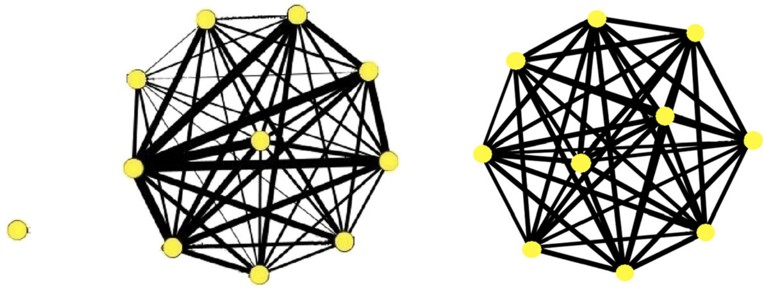


Fig. 6 Social network graph of students in Experimental Group A (*left*) and Experimental Group B (*right*)

productive metadiscourse. The first is *strategic* metadiscourse, concerned with planning next steps in an investigation, identifying needed information and how to obtain it. The other two kinds are discussions of epistemic actions as indexed by the Epistemic Discourse Moves tool and discussions of domain vocabulary prompted by the Word Cloud Tool. Grade 2 students in the experimental group were able to interpret information provided by both types of visualizations quite easily and actively discussed it. They often read the data presented out loud, or walked up to the visuals to gesture and point towards particular areas of interest.

Strategic metadiscourse

Evaluating strategies and planning further actions are important functions of metadiscourse in knowledge building/knowledge creation at all levels. We are not aware of any technological supports for strategic metadiscourse as distinct from general supports for inquiry (e.g., Quintana et al. 2004) or design (e.g., Pauwels et al. 2013). Teacher-student collaboration in strategizing is illustrated in the following dialogue excerpt:

> Teacher: …so what things [about feathers and flight] do you still have questions about?
> Student A: How do they learn to fly?
> Teacher: How do you think you can learn about that?
> Student B: Watching a mommy bird fly?
> Student C: I think we can because when we were um, in SK, we were making our own, um, birds, like birds, and then since birds have hollow bones, most of us didn't make like how we thought were hollow bones. But one of us, they used toilet paper rolls, and that was hollow, so it would farther because the wind went right through it.
> Teacher: So think about this. What would you do to go and find out about how they fly? One thing [Student A] pointed out was maybe designing some experiments. What other ways? Oh and I think [Student B] was referring to the fact that you might observe birds learning how to fly, so you would maybe do some experiments, maybe observe. How else might you find out how birds fly?
> Student D: You could look up a book about it.
> Student C: Maybe we could look up archeological trips because maybe that will tell us how, they learn how to fly because those evolve into birds.
> Teacher: So, looking at bird ancestry, ok!

The teacher's comments in this excerpt represent the kinds of statements she would make in KB talks, comparison and experimental classes alike—inviting continual questions, prompting students to think about next steps, re-iterating their ideas to help them plan possible next moves, and rearticulating and clarifying student statements. The teacher's support in helping students elaborate what they did not yet fully understand proved to be the most effective driver of metadiscourse concerned with troubleshooting and planning next steps.

In the experimental class, Word Cloud visuals acted as an aid to troubleshooting and planning. For instance, in one session students viewed an "Our Words" word cloud dealing with salmon reproduction. The largest word in the visual was "eggs," which prompted the teacher to ask the students why the word "eggs" appeared so large. The students recalled that they had been asking "why do salmon lay eggs?" (a question that appeared repeatedly in the online dialogue). In the following excerpt the student is not able to identify what is puzzling about egg laying, but her repeated emphasis on "WHY?" communicates a concern that a more sophisticated student might express as "Why is reproduction by means of eggs so widespread in the animal kingdom? Why don't all animals reproduce the way mammals do?"

Teacher: There it is again. Why do salmon lay eggs? What's so tricky about that question?
Student C: Why do salmon lay eggs? Well it's sort of the same as birds, and with everything that lays an egg. Well, WHY do birds lay eggs? WHY do salmon lay eggs?

Whether stated simply or elaborated, the *why* question can serve as a driver and give direction to further knowledge building.

Discussions of epistemic discourse moves

The Epistemic Discourse Moves tool, used only in Experimental Group B, served as a basis for metadiscourse concerned with what students were and were not doing in their knowledge-building work and how they might improve it. The following discussion ensued when the teacher asked group B how they had used Knowledge Forum the previous year:

Student C: You just type things that you want to know. And the whole page is filled with theories and questions.
Teacher: Your whole page is filled with theories and questions…
Student E: We only did like 5 of them or 10 "I knows" or facts, and like 50 theories, and I'm guessing like 30 "I don't knows."
Teacher: So, a lot of theories, and a lot of "I need to knows," but not a lot of facts. Why do you think that is? Why do you think there are a lot of theories? And maybe not so many "I knows" or facts.
Student A: I don't know.
Student G : Because there was a lot of "I think this," "I think that…," but there was no "I already know this...."
Student H: It's because, um, theories, many people don't really know for sure if it's actually real.

The students thus were able to discuss their use of Knowledge Forum scaffolds. When asked to reflect on the value of the feedback to her students, the teacher observed, "Some of my more verbal students were able to articulate the importance of looking at the graph to help determine which scaffolds to use when creating new notes. They saw the graph as a way of informing them about what notes they would need to write so that more information could be developed and shared." When the Epistemic Discourse Moves tool was introduced, it gave them a basis for more accurately evaluating what they had been doing. The following discussion occurred on first exposure to a graph generated by the Epistemic Discourse Moves tool. Various students spoke in rapid succession:

Student: I know what it is…[the graph]
Student: It's like a scale to see how much people used any of the scaffolds.
Student: So 'my theory'—5… a little more than 5.
Teacher: What were the 5 what?
Student: A little more than 5 people used it. 'I need to understand'—a lot, a little more than 15. Um, 'Important information + source' like 0 people used…
Student: More than 15 people used 'I need to understand'…

> Researcher: Actually these … it's actually notes. So how many notes have this scaffold in it?
> Students talking together: More than 5… 6… 'I need to understand' more than 15… 'Important information + source' more than 0 but less than 3… 1 or 2…
> Researcher: Well, this is actually a graph about you guys.
> Student: How much people used that.
> Researcher: So what does that tell us about us? […]
> Student: Maybe 1 person used 'Important information + source'
> Student: Huh, so it tells us that, it tells us about us that we like to write 'I need to understand' a lot…
> Student: Yeah and we [#] not that much 'my theories' and we [?] a little important information…
> Teacher: When would we be starting to write about 'important information + source'? when would we be starting to write about that?
> Student: First we have to really know some… and even if it's wrong we have to know that that's right…
> Teacher: We have to believe that that's right?
> Student: Like if it's wrong… like if it's right that's good but if it's wrong we should try our best to make the important information right because then we would think… because we'll say that… that's true but it's actually not true so…

Further discussion dealt with different ways of obtaining new information, with some students drawing on what they had been told the year before in grade 1.

Vocabulary discussions

Students were able to quickly interpret the difference between the three types of clouds provided by the Comparative Word Cloud tool ("Our Words", "Expert Words" and "Our Shared Words"). They interpreted the word cloud visual with little instruction, pointing out that the larger the word appeared in the word cloud the more frequently that word was used in the source data. Students appeared to like identifying new and challenging words, and would typically gesture toward and read out loud the words they did not recognize. The teacher commented as follows on the value students found in viewing Word Clouds:

> They identified specific words that they used more often in their notes and they talked about how those words were a reflection of how important those words were to their understanding of birds or salmon. In addition, the word clouds helped the children to see that they were using the same kinds of vocabulary as the experts.

Learning more about key vocabulary became a welcome task. For instance, occasionally, after discussion time was over and students could begin writing on Knowledge Forum, they formed small groups or paired off to seek out texts from which they could learn more about the new words just discussed. Overall, students were not discouraged by new and challenging words they did not understand but repeatedly took an interest in discovering the meaning behind unfamiliar "expert" terms. They were motivated to engage with the terms on their own and performed the important service of introducing relevant and challenging words into the community dialogue.

Nomenclature issues are an integral part of knowledge creation in the disciplines, and so discussions of word meanings and usage are usually closely connected to substantive issues and are seldom carried on purely as metadiscourse—"discourse about the discourse." This was true of the students in this study, with the result that vocabulary discussion tended to merge into regular knowledge-building discussion. For instance, the discussion quoted earlier, about ways of obtaining information on how birds learn to fly, was initiated by a student's noticing something about use of the word "feathers":

Student A: They [experts] don't use 'feathers' as much as us.
Teacher: Why were we using feathers so much? What did we learn?
Student A: We learned how, where the different parts… so there's different feathers and they have a special place where they go. Let's say if the tail feather went on the wing, something will happen.
Teacher: Hmmm
Student B: We were talking about design…

However, sometimes discussion centered on a word itself and its meaning in relation to their inquiry. For instance, during one session, two students noticed the term "drag" on the "Expert Word" cloud dealing with the question "how do birds fly?" Afterwards these students looked up the term in a classroom book and then signed into Knowledge Forum to enter what they found: "*Important Information + Source: When a bird is dragging their feathers it is slowing itself down. It is called a drag.*" Shortly after they contributed this note, another student added the question: "*I need to understand: What do birds use to make a drag*"? This same student also posed a theory about the concept: "*My theory: I think that birds drag on walls.*" In this case, the students did not succeed in nailing down the aeronautical meaning of "drag" or distinguishing it clearly from its everyday meaning, but they apparently did achieve the third level of Stahl's (2003) four levels of word recognition: recognizing the word as being used in the context of explaining flight and having something to do with slowing down, but not yet locating it in the proper ontological category, which is that of a force, not an action. This example shows students actively integrating a new and challenging term into their discourse and, perhaps more importantly, building onto a simple definition with their own ideas.

A total of 36 % of the words appearing on the Expert word clouds were also present in the students' online dialogue. Students used the terms in questions, theories and when introducing new facts. The following examples from student notes illustrate use of the "expert" words: *coniferous, navigate, alevin, fry, parr, smolt,* and *redd*:

- Why do owls have to be surrounded by coniferous trees?
- Bird's can't navigate at night and they can crash.
- "Important information + Source" The Life Cycle of a Salmon: A salmon first the mother salmon has salmon eggs then the eggs turn into alevins and then they turn into frys then they turn into parr and then they turn into smolts, then they turn into fully grown salmon and mature salmon!!
- "Important information + Source": salmon are orange because they are camouflaged against their enemies. Chris Robinson told us that.
- "Important information + Source": redd means a shallow nest dug into gravel by a female salmon.

However, new words tended to appear more frequently in oral discussion than in online notes. For instance, the following statement by an Experimental Group B girl made substantial use of the new word, "migrate," yet that word appeared only once in the written discourse of the whole class:

> I have the answer to the question about why salmon go to the sea at all…like, birds they migrate, and so do salmon. When they migrate to the sea that's migrating from the rivers because the rivers get colder in the winter and sometimes they can freeze but the ocean can't freeze so they go to the ocean and then when it's time, they go back because in rivers there's lots of rocks so it's easier for them to hide and they can lay their eggs and not a lot of things can see them…

Overall, students were engaged by new terms and worked to build an understanding of new words in relation to their inquiry, embedding them meaningfully within an existing dialogue that helped them make sense of these challenging terms in their knowledge building work.

The productive role of new "expert" vocabulary can be seen in a comparison of two online "inquiry threads" (Zhang et al. 2007), one from the comparison and one from the experimental class, both pursuing the question "How do birds fly?" This question came up repeatedly in the experimental class, and was salient enough among students in the comparison class that they created an entire Knowledge Forum view dedicated to it. In the discourse of the comparison class, the inquiry on birds and flight began when one student asked: "*how come some birds can fly but others can't?*" What followed were a number of theories and ideas, including the following: birds need hollow bones in order to fly; some birds are better at swimming and running; birds that are too heavy cannot fly; and birds that get their wings wet or have short wings cannot fly. Students also began researching the question and introduced new information into the dialogue, such as the following: "*Important information + Source: some birds have more wings than other birds,*" or "*Important Information + Source: their honeycomb bones make light and it helps them fly.*" Students also utilized impressive terminology when they made fact-based contributions to the dialogue, as in this child's note: "*My Theory: birds of prey glide in circles on thermals to climb without wasting energy.*" As the dialogue about how birds fly progressed, focus fell heavily on the role of feathers in enabling flight. Discussion was marked by consensus that feathers allowed birds to fly, but also included questions that could extend the discussion, such as: "*how can birds fly with lots of heavy feathers on?*" As these excerpts show, the comparison class posed a number of promising questions and ideas about flight, and also used advanced terminology in the dialogue on repeated occasions. However, while the students proposed a range of important theories addressing the central question of how birds fly, they did not elaborate on these theories to probe deeper questions or connections to their own ideas. For example, students neglected to ask *how* feathers help birds fly, or how the idea of "gliding" relates to feathers. Comparison class students did not expand their vocabulary to include other concepts and terms important in understanding flight, such as "drag," "lift," "upstroke," and "aerodynamic."

In the experimental class, students' initial ideas about how birds fly were similar to those from the comparison class: birds' wings help them to fly; the wind keeps birds in the air; birds' feathers help them to fly; and, birds can fly because they are light. In the following weeks, however, experimental group students built on to their initial ideas, particularly in developing the idea that feathers are important in enabling birds to fly. One student posed the idea: "*My Theory: I think that the design of their feathers helps them to fly.*" Another student built onto this theory by adding a small but useful detail: *"My Theory: The shape of the feather is curvy.*

That helps it to fly.” Other students introduced more ideas: *“Bird’s feathers are like parachutes,”* and “*New Information + Source: the wind goes over the bird’s body and help the bird to fly.”* Also, as in the comparison class, newer, more refined questions emerged from the discourse as it progressed; for example: “*I need to understand: how birds take off when they are going to fly? My Theory: is I think they just lift their wings and flap up and down, and with their tail feathers they can go left, right, up and down and that’s how they steer, the wings help them take flight and the tail helps them steer.”* Students were also using the new words they encountered in the word cloud feedback into their comments, as discussed previously. In the discourse of the experimental class the students’ sustained focus on the role of feathers in enabling flight helped them to speak more specifically about particular attributes such as a “curvy design,” incorporate relevant terms like “steer” and “drag,” and open up their discourse to new paths by probing new concepts—for instance, the final question about “what makes a drag” calls for exploration of the interplay of air currents and wind with the design of feathers and wings. While the students’ discourse does not extend to include these sorts of considerations, the fact that their own discourse led them to such a point reveals that these students were moving their dialogue in productive and promising directions and were applying important terminology in relevant and useful ways.

In summary: In both the experimental and comparison classes (both of which had discourse supports provided by Knowledge Building pedagogy and Knowledge Forum), grade two students showed evidence of ability to devote sustained attention to problems of explanation and to generate a number of promising ideas and sub questions. The principal effect of the group-feedback and metadiscourse interventions seems to have been to help the students elaborate their explanations (called “theories”) by bringing in new domain vocabulary and creating a somewhat more complex network of explanatory ideas.

Discussion

The primary question pursued in this study was whether formative feedback in the form of visualizations of discourse in community knowledge spaces could help young students carry on productive metadiscourse—discourse that evaluates, strategizes about, and shapes the direction of their main knowledge-building effort. Our findings support a qualified “yes.” Affirmative, although indirect evidence comes from quantitative data showing that interventions aimed at supporting metadiscourse resulted in greater “scientificness” and complexity of explanations, use of more advanced vocabulary, an increase in contributions of types previously neglected, and a more closely interconnected communication network among students. More direct although more subjective evidence came from records of the students’ oral and written dialogue, which showed definite evidence of metadiscursive capabilities. A necessary qualification of the “yes” answer, however, comes from the active role the teacher played in the metadiscourse. In a few instances the students carried out such discourse on their own, especially with respect to new word meanings, but the general conclusion we may draw from current results is that students as young as age seven are capable of productive metadiscourse, although not independently. This conclusion still implies a greater capacity for “meta” processes than such young students are usually thought to have and demonstrable value in promoting such thinking at this age.

The other research questions concerned the effectiveness of group-level formative feedback to support metadiscourse. Teacher-facilitated metadiscourse about the students’ knowledge-building inquiries was combined with use of visualizations providing feedback on vocabulary and epistemic marker usage in the students' online knowledge-building discourse. The measured effects of this combined intervention included gains in the quality of knowledge-building discourse, use of domain vocabulary, and density of the students' communication network. Classroom observations indicated the visualizations were readily comprehended by 7-year-old students. They showed a high level of engagement with them, often physically interacting with them. For instance, as soon as the Comparative Word Cloud visuals were put up, students would begin reading the words depicted out loud, often choosing to sound out the unfamiliar and difficult words. They would also often walk up to the word clouds, point to words as they read them aloud, measure word sizes with their fingers, and compare sizes of words. Thus the word cloud visualizations quite directly influenced the students' metadiscourse and motivated further inquiry into concepts represented by the "expert" words. Results with the Epistemic Discourse Moves tool indicate it served its intended purpose—to increase the range of students' knowledge-building discourse moves—although the increased use of information and evidence moves did not apparently raise the quality of their theories above the effects associated with the vocabulary intervention.

Caution is advisable in generalizing from these results. Besides the well-known limitations of time-lag experimental designs (Campbell and Stanley 1963), there is the non-representativeness of the student population. Most of the students in the study came to grade 2 having already had 2 years of experience in an educational environment that emphasized inquiry and student agency and where the average level of literacy was fairly high. Results comparable to those obtained in this study might therefore not be readily attainable in a wide range of grade two classes. Current research is extending the interventions tested in this study to more diverse student populations. We suggest that the results of the present study be interpreted within the framework of Kurt Fischer's theory of cognitive development (Fischer 1980; Fischer and Pipp 1984), where "optimal" performance, observed under highly supportive conditions is taken to indicate potential, whereas "functional" performance can vary over a range of ages.

Vocabulary as a focus of metadiscourse

Metadiscourse—discourse about a discourse—often focuses on social practices: turn taking, paying attention to other speakers, considerateness, and so on (Vande Kopple 1985; Baltzersen 2013). Although these are important concerns in any discussion, in Knowledge Building/knowledge creation the more salient concern is whether the discourse is making progress toward a knowledge objective. In the present study the teacher helped steer the discussion in that direction, a typical question being "What are things we still don't understand?" Students' responses to teacher questions, along with their own self-initiated use of the "I need to understand" scaffold suggest students are capable of identifying knowledge needs and able to bring their own feelings and intuitions to bear in identifying knowledge gaps and taking next steps. Some of the most active and productive discussion concerned vocabulary, as represented by the Comparative Word Clouds tool. Because such discussion was generally closely tied to substantive issues such as explaining how birds fly, a question may arise as to how "meta" such discussion is. We can well imagine knowledge-building discussions among adult theory-builders where definitional issues would be so integral to explaining and model building that they would in no way constitute a meta-level of discourse. See, for instance, Lakatos (1976), where the resolution of theoretical difficulties due to negative evidence is accomplished by redefining mathematical terms. With young students, however, discussion of domain vocabulary more clearly involves a widened perspective on their knowledge building, and so may properly be regarded as metadiscourse. As both quantitative and observational results indicate, discussion of domain vocabulary was a particularly effective form of metadiscourse. It is noteworthy as well that the Experimental Group formed a much more highly interconnected social network on the basis of lexical co-occurrence. Research by Haythornthwaite and Gruzd (2012) showed that network actors who exhibit more connections to other actors are more likely to receive information that is available in the network, and are also more likely to exert influence on others, whereas actors who are peripheral or isolated in the network are less likely to access resources and be involved in discussion. Results from the present study provide evidence that even quite young knowledge-building students are capable of creating networks that are rich in "social capital"—which, from a social network perspective, refers to a group of participants that "hold within their membership the social means to respond in need" (Haythornthwaite and de Laat 2012, p. 355).

Group-level feedback as formative evaluation

Individual learning gains (in vocabulary and in scientificness and complexity of explanations) resulted from feedback that was non-evaluative and that described group rather than individual behavior. Formative evaluation based on this feedback was done by the students themselves, not by the technology or by the teacher. There is nothing remarkable about group-level formative evaluation, as such. Teachers do it all the time. They judge that their class is or is not understanding something, that motivation is high or low, that progress toward a learning objective is fast or slow, and they make strategic decisions on the basis of such evaluations. Technology provides little support for such evaluation, however, apart from instructional management systems that will administer and score objective tests. Educational testing of all kinds is focused on individual performance and at most delivers group averages of individual scores. Group cognition (Stahl 2006) has yet to find a place in educational assessment, despite the fact that in today's knowledge-based and innovation-driven societies virtually all knowledge advances are group endeavors.

The two group-level feedback tools developed for and used in the present study are very modest ventures into the domain of automated group-level assessment, but they serve to illustrate key ideas that could inform future development of more sophisticated technology:

- The idea of group cognition itself—the idea that groups may have cognitive states, capabilities, functions, and ways of behaving that cannot be decomposed into individual variables. The use made by young students of group-level feedback from the tools used in the present study demonstrates that a group may have a vocabulary that is not a sum, average, or other combinatorial function of individual vocabularies and that a group may favor certain kinds of individual contributions above others.
- The idea of technology that describes but does not itself evaluate, instead providing information to aid evaluation.
- The idea of feedback to selected modifiable aspects of a process rather than to the central process itself. Vocabulary and epistemic discourse contribution types are both aspects of group discourse relevant to knowledge advancement, but neither alone nor in combination do they directly measure progress in the creation of domain knowledge.

- The idea of feedback that points forward rather than backward to deficiencies that need repair. In the present study feedback tools served to suggest words and discourse moves beyond the students' current repertoire rather than simply evaluating their work so far.
- The idea of transparency. Although automated semantic analysis, for instance, is able to provide potentially useful information about the content of students' discourse on a topic, it does so by processes that are invisible and largely incomprehensible to students and teachers. Feedback based on countable events (such as vocabulary usage and use of epistemic markers, as in the present study) is readily comprehensible even by young students and can serve as a basis for productive metadiscourse.
- Finally, the idea of student agency in formative evaluation. Self-assessment enjoys considerable popularity in education (Boud 1995; Chappuis and Stiggins 2002; Ross 2006; Andrade and Du 2007), but as with test-based assessment it focuses on individual performance. Experience with metadiscourse in the present experiment encourages the belief that students acting as a group can effectively assess and reflect upon their performance as a group and that this can lead to knowledge advances.

Individual assessment is not going to go away. There are a number of forces supporting it, not least of which is parents' natural concern with how their particular child is doing. However, individual assessment does not need to dominate educational assessment the way it does now. Particularly for students, the question "How am I doing?" needs to be supplemented and on a day-to-day basis by the question, "How are *we* doing?" Group-level formative feedback should help answer that question and give focus to the questions individual students should ask themselves: "How am I contributing to this effort? How could I help the group move ahead?"

Directions of further development of group-level feedback in knowledge building

The study reported here was of small size and with limitations on generalizability already noted. From the standpoint of CSCL design, it serves as a pilot study of ways to support metadiscourse in knowledge building by young students. From this standpoint, the results are promising and suggest the value of incorporating metadiscourse-oriented pedagogy and technology into CSCL more generally. Several lines of advance beyond existing technology are suggested:

- *Incorporate feedback tools into the online environment*, and *design them to be operable and meaningful to the most naïve students likely to use the environment*. Having tools such as the Comparative Word Clouds and the Epistemic Discourse Moves tools available on demand within the online discourse environment should reduce the need for special sessions devoted to metadiscourse and make it an integral part of collaborative knowledge building/knowledge creation, as it is in professional teams.
- *Make the tools applicable to oral as well as written discourse*. It was observed that experimental group children made greater use of domain vocabulary in oral discussion than in their Knowledge Forum notes, and many knowledge-building teachers have remarked that the complexity and diversity of ideas students produce in oral discussion is greater than in their writing. Bringing oral discourse into the formative assessment process involves video or audio recording, speech-to-text conversion, and speaker identification, all of which are somewhat problematic with current technology. However, group

level assessment allows greater leeway in these regards than individual assessment. Because of the large amount of data being aggregated, higher error rates in speech recognition are tolerable and—although desirable for some purposes—it is not essential to identify speakers. In group-level assessment, what gets said is, for many purposes, more important than who said it.

- *Develop automated recognition of discourse contribution types*. Such development will likely involve an iterative process of discovering semantic markers to distinguish different types of discourse contributions (e.g., distinguishing contributions of evidence related to a hypothesis from contributions that merely present topically relevant information) and revising the categories of contributions to accord with what can be accurately identified. The Epistemic Discourse Moves tool used data from the students' selection of scaffolds (more precisely characterized as "epistemic markers"). In the interests of usability, such markers were few in number and simply worded. Results attributable to the discourse moves tool were limited and apparently did not extend to influencing the overall rated quality of notes. There are already research tools that can identify discourse topics and epistemic roles (e.g., Jeong 2009; Halatchliyski et al. 2014). The challenge is to make their underlying logic sufficiently transparent and comprehensible that they overcome their "black box" character and to find readily comprehensible visualizations of results (comparable to comparative word clouds) that give students a meaningful perspective on their own work that they cannot get from ordinary observation.

Conclusions

This study has opened several windows on the knowledge-building capabilities of young students:

- First, it shows that metadiscursive reflection, when given suitable support, is within the scope of what young children can do in working creatively with knowledge. In short, they can do more than brainstorm, which is what creative idea work often amounts to in the early school years.
- Second, it shows there is potential for feedback tools to address group cognition and to provide information young students can actually use in formative ways.
- Third, it opens an important avenue for a larger design research program, which includes inter-related innovations having to do with "promisingness" (Chen et al. 2012), "idea threads" (Zhang, et al. 2015), and various social-semantic network analyses, in addition to the tools introduced in this study.
- Fourth, it shows that children can take an active role in their own vocabulary development.

Although vocabulary growth is gaining recognition as a vital part of literacy development, the most ambitious instructional programs only manage to teach a few hundred words a year, against a background of thousands of words acquired through ordinary experience (Biemiller 2005). This study shows young children adopting new vocabulary for a purpose, which might be the way intentional vocabulary growth should be pursued in education. In addition, there is evidence from use of the Epistemic Discourse Moves tool that students can extend their repertoire of discourse moves—a potentially significant finding. Arguably, the most significant finding is that tools that open up these possibilities for students are engaging, for teachers and students. The teacher was clear that she was able to see and accomplish things that she could not accomplish without the meta-perspective provided by group-level feedback. Moreover, the sessions engaging teachers and students in discussions were consistently viewed as enjoyable and productive.

We see possibilities for a higher norm for knowledge-building discourse as new analytic tools are integrated into Knowledge Forum, allowing users to crisscross the landscape of ideas from multiple perspectives (Scardamalia and Bereiter 2015) and thereby enrich the problem space within which knowledge-building metadiscourse takes place.

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