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RESEARCH ARTICLE

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Knowledge building: idea-centered drawing and writing to advance community knowledge

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Abstract

This study explores the dynamic, interactive nature of digital drawings and writing in a knowledge building community in which students used a multimedia online environment—Knowledge Forum—to represent and advance ideas in the field of optics. The research employs a mixed-methods case study to collect and analyze multimedia notes created by 22 fourth-grade students. Graphical notes—notes containing drawings—included more idea units and more sophisticated ideas than non-graphical notes. Quality of drawing also correlated with idea improvement in Knowledge Forum notes, with ratings of idea improvement based on conceptual understanding of optics. Overall, findings revealed significant advantages of online drawing for Grade 4 students, with case-study analysis revealing the many ways in which graphics complement writing and contribute to knowledge building.

Keywords Graphics · Drawing · Graphical literacy · Knowledge Building · Digital writing · Idea-centered writing · Elementary education · Learning communities · Knowledge Forum · Multimedia

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Overview

The importance of writing to convey and advance ideas—what we refer to as idea-centered writing—is well documented (e.g., Davis & Hult, 1997; Graham et al., 2016; Durst & Newell, 1989; Wittrock, 1992). Writing difficulties for school-age students are also well documented (Little, 2003; National Center for Education Statistics, 2012; Westwood, 2008), especially writing to serve goals of idea improvement (Bereiter, Bogouslavsky, Tsuji, & Scardamalia, in press). Difficulties have motivated a search for effective strategies to develop writing skills (Graham & Perin, 2007), idea-generation (Galbraith, 2009; Van den Bergh & Rijlaarsdam, 2007), and knowledge transforming approaches to written composition (Bereither & Scardamalia, 1987; Scardamalia & Bereiter, 2012).

This research explores the knowledge transforming—Knowledge Building—approach. Knowledge Forum is a multimedia computer-based environment designed to support Knowledge Building through use of text, graphics, video, and other representational forms to record and improve ideas. Current claims regarding the efficacy of Knowledge Building are based largely on text analysis (e.g., Chen et al., 2017; Lin & Chan, 2018; Oshima et al., 2020). Thus while drawing has been shown to support children's literacy development (Mackenzie, 2011), its contribution to knowledge building has not been investigated.

After a brief account of Knowledge Building/Knowledge Forum, we discuss research bases for the profound influence drawing may have on idea-centered writing. Such research is of growing importance as multimedia environments become increasingly available and essential for knowledge work, not simply in school and across disciplines, but also in workplace settings. Yet as we indicate, there is a lack of research regarding ways in which graphical representation of ideas may facilitate idea development and written composition, and more specifically its role in knowledge building. Thus, we discuss drawing as a planning tool and medium for idea-centered knowledge work with special benefits for writing, and end the introductory section with the rationale, research design, and goals for the study to be reported.

Knowledge Building and Knowledge Forum representing and advancing ideas

Knowledge Building requires meaning making (Steffe & Gale, 1995), as with constructivist pedagogies broadly. Beyond understanding and application of given information, it also requires that students generate artifacts and engage in sustained creative work with ideas to advance community knowledge. It is in this sense that students are engaged in deep constructivism—taking high-level responsibility for knowledge-creating work (Scardamalia, 2002; Scardamalia & Bereiter, 1994, 2010). In establishing and advancing knowledge building communities, teachers engage students as partners in an enterprise for which they share *collective responsibility for community knowledge*. That responsibility is reflected in contributions to community resources, most visibly in the current study through representing and continually improving ideas in Knowledge Forum—the multimedia environment specially built to support Knowledge Building (Scardamalia & Bereiter, 2003). In line with work in knowledge creating enterprises beyond school walls, students are generating and advancing the knowledge assets of their community. They focus on improving ideas and representing advances in ways accessible to others, as opposed to working on a series of assigned tasks and activities. Ideas are improved in various ways to achieve the community's shared goals. Toward

that end students identify problems and questions to be addressed; design experiments; find, read, and contribute new information from books and web resources; take field trips, talk with experts, and assemble and review new information from many sources; and meet to discuss findings and next steps.

The multimedia environment provides the community space where community members share and advance ideas. Knowledge Forum includes specialized tools to foster knowledge creation. For example, there are scaffolds to support advanced discourse forms such as theory building, problem identification and idea improvement; rise-above notes to encourage explanatory coherence; drawing tools to produce models and illustrations; reference links to access source material; and analytic tools to view progress and create higher-order representations of their work. Students are afforded time for research-intensive efforts required for sustained creative work with ideas, especially idea-centered drawing and writing.

While each student is producing notes, they are not focusing exclusively on individual performance. They read, build on, and reference each other's contributions, providing an audience beyond the teacher for their work—something largely lacking in school writing contexts. They can invite visitors from outside their community into their community space or link to community spaces beyond classroom walls. They can co-author notes and views for discussion in Knowledge Forum, so it is easy for students to form into small groups to address specific issues. To support idea-centered knowledge-building communities, Scardamalia (2002) explicates 12 principles. Here we introduce four principles that are particularly focused on generation and improvement of ideas: (1) "real ideas, authentic problems" (students identify problems they really care about—things they wonder about and cannot explain—related to their real-world experiences and contribute them as building blocks); (2) "idea diversity" (diverse ideas are generated by community members, creating a diverse pool of ideas to explore); (3) "improvable ideas" (all ideas are treated as potentially improvable and through collective questioning, research, integration, etc. students advance their ideas); (4) "rise above" (students create higher-level syntheses and deeper understanding). While we mention these four, all principles interact synergistically, with focus on different facets of knowledge creation such as constructive uses of authoritative sources and concurrent, embedded, and transformative assessment.

Given the benefits of drawing for prewriting, representing ideas, idea generation and improvement, a digital drawing tool is built in Knowledge Forum. With the drawing tool, and other multimedia capabilities (audio, video notes), Knowledge Forum supports multiple external representations of ideas (Hong et al, 2020). Through use of the digital drawing tool students draw pictures, diagrams, models, accounts of experiments they conduct, and so forth. Graphical literacy and conceptual understanding are mutually reinforcing (Gan et al, 2010). With the rapid development of multimedia and network technology for learning, integrating drawing with digital text has become important for online learning (Dziedziewicz et al., 2013; Knight & Dooley, 2015; Matthews & Seow, 2007; Selwyn et al., 2009). Yet the ways in which online drawing could be used to support continual idea improvement remains poorly understood (Chen & Hong, 2016). As Knowledge Building attributes much importance to idea advancement, it provides a venue for investigating Knowledge Forum's digital drawing tool to support the multiple representations of students' ideas in writing. While researchers have argued that the overall Knowledge Forum experience can lead to gains in graphical literacy (Scardamalia & Bereiter, 1993), much work is needed to understand the intricate relation between digital drawing and text production (Carroll, 1991).

Drawing: prewriting and idea generation

According to Calkins (1986), "[t]he act of drawing and the picture itself both provide a supportive scaffolding within which the piece of writing can be constructed" (p. 50). Drawing has thus been viewed as a valuable pre-writing planning activity (Halperin et al, 2013; Mavers, 2011). Children's writing skills have been improved through combining creative drawing and writing. Advantages are attributed to visual support provided by graphical images and, in turn, to more intuitive means of expression, more sophisticated vocabulary brought to mind, and enthusiasm created for writing (Brown, 2013; Yuan & Brown, 2015).

In a review study, drawing was identified as one of eight learning strategies to promote generative processes supported by writing (Fiorella & Mayer, 2015, 2016). In line with this finding, reading or writing tasks incorporating student drawings led to elaborating new concepts (Chuy et al., 2012; Wittrock, 1992) and improved learning (Fiorella & Mayer, 2015; Leutner & Schmeck, 2014).

Drawing is a way to gather and organize ideas in advance of writing (Caldwell & Moore, 1991; Mavers, 2011), and thus to facilitate planning. To access content relevant to writing, a metamemorial search must take place (Bereiter & Scardamalia, 1982). Drawing facilitates metamemorial search and, in turn, planning and finding a starting point. Drawing is thus a form of prewriting and an aid for focused attention on content for writing (Halperin & Smith, 2013).

In addition to use as a prewriting tool, drawing can facilitate communication of ideas in text as it provides an alternate form of idea representation. This is especially helpful at a developmental stage when students struggle with the mechanics of writing, as drawing provides external representations of ideas to extend cognition. A classic study by Carlson (1963) observed that fourth, fifth and sixth graders who were given visual stimuli (e.g., pictures and toys) wrote longer and more original compositions and used a wider vocabulary than students in a control group receiving no visual stimuli.

Drawings can help in representation of main ideas and generation of written summaries (Papandreou, 2014; Rich, 1994) and visual illustration has been found to facilitate conceptual recall, problem solving, and explanation building (Ainsworth et al., 2011). Writers additionally use drawing to illustrate details and subtle properties, thus augmenting written presentations of scientific concepts and laws. On the reader's side, drawings promote reading comprehension because they provide concrete representations of objects that have been seen or imagined. The meaning of a graphical object can be discerned nearly instantaneous, because decoding graphical information requires less cognitive effort than decoding written language (Paivio, 2014). In other words, drawing can be more effective than text for communicating complex content, because processing graphics can be less cognitively demanding than processing text.

The broader perspective provided by graphical representation can contribute to more forceful voice, willingness to write more, and extended work on writing (Williams, 2014). Eisner (1981) asserts that children who have not explored their environment through a form of visual art—drawing, painting, and sculpting—may not be able to write, not because they cannot spell but because they cannot think of what to say. Drawing is integral to children's ability to express themselves and provides a medium to clarify changing conceptions of the world. Isolating drawing from writing eliminates use of graphical symbols to express and connect learning with lived experiences (Ainsworth et al., 2011; Brittain, 1979).

Young writers have difficulty writing cohesively (King & Rental, 1981; Puranik & AlOtaiba, 2012). Engaging them in drawing can help create an overview of ideas and

relationships between them, thus provide a holistic plan—a top-down overview of what they know or need to know about the topic. Thus drawing can facilitate cohesive writing in which ideas fit with one another more effectively than through "associative writing"—writing down whatever comes to mind in the order it comes to mind (Bereiter, 1980).

Drawing: external representation of ideas, mental models, and idea improvement

Drawing is one means by which students express their ideas, conceptions, and understanding of the world. Young children draw what they think or imagine (i.e., ideas), not just what they see. Drawing becomes a form of discovery through a mediated process of organizing and building ideas into mental models that facilitate meaning-making and understanding (Wright, 2010). Through graphical representation students can represent ideas without dependence on text production and realize the added benefit of improving visual ability (Mavers, 2011). As a nonverbal mode of expression, drawing can reflect children's thoughts and mental models and provide a medium for expressing emotions, feelings, and identities and they use graphical content to externalize their ideas. In many cases, drawing "brings the ideas to be verbalized bubbling to the surface" (Clay, 1979, p. 87), creating a visible, concrete representation of an idea that feeds back into the processes of refining the idea and creating new ones.

In Knowledge Building, young writers use drawings as a self-chosen form of representation through selection of a drawing rather than writing tool, as they are not required to produce drawings. In everyday life graphs appear on TV, the Internet, text books, and so forth, aiding idea generation and serving as reference points. This, in turn, aids expression through other media and generation of more cohesive compositions, as well as advancing graphical literacy (Gan et al, 2010). Scardamalia et al. (1982) found that when provided with external cognitive support, young children produce texts containing more words. Drawing is a form of mnemonic to prompt recall.

Drawing: a promising approach to help close gender gaps in writing

Boys have been shown to be less successful than girls in reading and writing (Collins et al, 2000; Evans, 1999; Jones & Myhill, 2007). Reasons for this presented in the education literature include the fact that boys are more likely to rely on visual media such as TV and computer games (Jones & Myhill, 2007) and to demand choice of what to write about and become discouraged when having to stay with a fixed topic (Myhill, 2001).

Drawing could help to reduce the gender gap in writing skills (Millard & Marsh, 2001). A previous Knowledge Building study regarding elementary students' online discourse revealed that both boys and girls equally contributed a substantial amount of text and graphics and the boys even did slightly better than girls in various literacy related measures, suggesting the potential of Knowledge Building to help boys overcome weaknesses in literacy (Sun et al, 2010). Wanstreet and Stein (2011) also argue that as knowledge building is highly collaborative, its effects depend more on the learning context than on gender. These studies suggest that collaborative knowledge building and digital drawing tools could eliminate or moderate gender gaps in writing. To explore this possibility, we analyze gender-related performance in writing.

Rationale of the study

The present study explores possible productive connections between drawing and writing, as reported in the literature (Puranik & Lonigan, 2011), and extends the investigation to an online environment designed to support knowledge building. The focus is idea-centered drawing and writing to provide a dynamic interactive framework for idea improvement. The work builds on the substantial literature about drawing's promise for facilitating writing and idea generation and aims to help fill the void created by the lack of attention to drawing in school curriculum (Steele, 2014). It additionally aims to characterize benefits associated with graphical literacy. Although there have been studies of the role of drawing in writing of preschool and elementary school age children, almost no published research on the effects of drawing on knowledge building (see Chen & Hong, 2016, for a review). Most existing studies concerning children's drawing and writing examine children's learning, drawing, and writing processes from an individual learning perspective (Gan et al, 2010). This study, in contrast, explores relationships between drawing and writing where collaborative knowledge-creating practices are highly valued. To what extent was student drawing in the study linked to students' writing and idea improvement? Answering this question could have important implications for designing better environments for learning and knowledge building. Further, the gender issues in relation to use of drawing and written language in a knowledge building environment remains largely unexplored and thus further research is warranted. These research gaps motivated us to explore the fourth graders' idea production and drawing and writing performance in the online knowledge-building environment.

The main research questions were: (1) To what extent is digital drawing, used as a means of externalizing and representing ideas, associated with the writing performance of fourth-grade children in a knowledge-building environment?, (2) To what extent is digital drawing associated with students' generation and improvement of ideas in a knowledge-building environment?, (3) Are there gender differences in fourth-graders' drawing and writing?, (4) What functions does drawing serve in generating and advancing ideas in writing?

Methods

Study design, participants, and context

A mixed-methods case study design was used to examine Knowledge Building in a fourth-grade class to generate detailed accounts of drawing and writing activities (Crowe et al., 2011). Participants included 22 fourth-grade students (11 girls and 11 boys) from a primary school in Toronto, Canada. They studied optics for 16 weeks. They received no special training in writing or drawing before the study, but participating students already had one-year experience in Knowledge Building in grade three, so they were familiar with the basic functions of Knowledge Forum.

The knowledge building setting

In the school where this study took place, Knowledge Building, supported by Knowledge Forum technology, is an integral part of the educational program, enabling extended work

in different fields of study. The teacher often identifies a broad area of inquiry such as optics and engages students in discussion to tap into what they wonder about and would like to understand. For example, for optics they may wonder: How do rainbows form? What keeps blind people from seeing? Why is the light in the classroom flickering? They are encouraged to explore issues they care about and find points of interest and work toward explanatory coherence (Thagard, 2000) across different explorations.

Throughout their engagement in Knowledge Building, face-to-face conversations known as "KB talks" take place several times a week and provide opportunities to tackle challenges as a community. Students have time to post ideas in the form of *notes* and to create *views* of their work*,* as elaborated below. Typically, the teacher does not assign specific learning tasks or require the students post a certain number of notes or words. Rather, students are encouraged to express their ideas, wonderment, and discoveries and these drive the work forward, with new explorations following from early ideas deepened through new information found in books and web searches, through experiments (often design by the students), field trips, and discussions with peers and possibly experts.

The teacher, as a member of the community, provides guidance as needed, often modeling sophisticated knowledge work. In this particular case, for example, the teacher engaged students in decisions regarding next steps, conversed with them about his own wonderments and things he did not understand, mentioned readings they might find helpful, and reflected on progress. He conveyed appreciation for their accounts, as expressed in notes and during "KB Talks," of what they did *not* understand. He also modeled efforts to find ways forward and improve ideas, using expressions such as "So, let's see—can we actually state our knowledge advances?" "How could we figure that out?" "You are right; we actually have not explained that; it's great that you noticed!" More generally, he encouraged students to take collective responsibility in identifying problems of understanding, noting when they were stuck, reflecting on their progress, and defining next steps.

Since ideas are recorded in Knowledge Forum, connections across areas of inquiry can be explored easily. So while students typically work in small groups on a Knowledge Forum view corresponding to particular challenges, they see the larger picture of work by discussing work across views.

Figure 1 shows examples of Knowledge Forum views and notes. There are three layers in this figure. The background layer shows the initial view in which students discussed light in general. The middle layer shows a later view on the more specific theme of "Natural and Artificial Light." In both sample views, a square represents a Knowledge Forum note and an arrow indicates a temporal discourse relationship (see "Built-on notes in Fig. 1). A "Rise above note" includes student summarization of a set of notes enclosed in the rise above; for example, students bring together notes about rainbows (e.g., How are rainbows made? What are rainbows made out of? Light is like a ball.). Students can tell if they have read a note as it turns red. They can link different views by simply dropping "view links" into views.

The foreground layer shows the content of a sample note. Notes have three text areas: problem statement, note title, and note content and students can choose to co-author notes. In this example the note is titled "Rainbows", the problem statement is "How are rainbows made?" and the note content shows use of scaffolds—customizable supports for high-level discourse within Knowledge Forum. In the example shown in Fig. 1 the scaffolds "Our understanding…" and "What we still do not understand…" (designed through teacher-student collaboration) are used.

The selection palette for the digital drawing tool that the class used to represent ideas graphically is shown in the foreground. Students are free to create a graphic or text note,
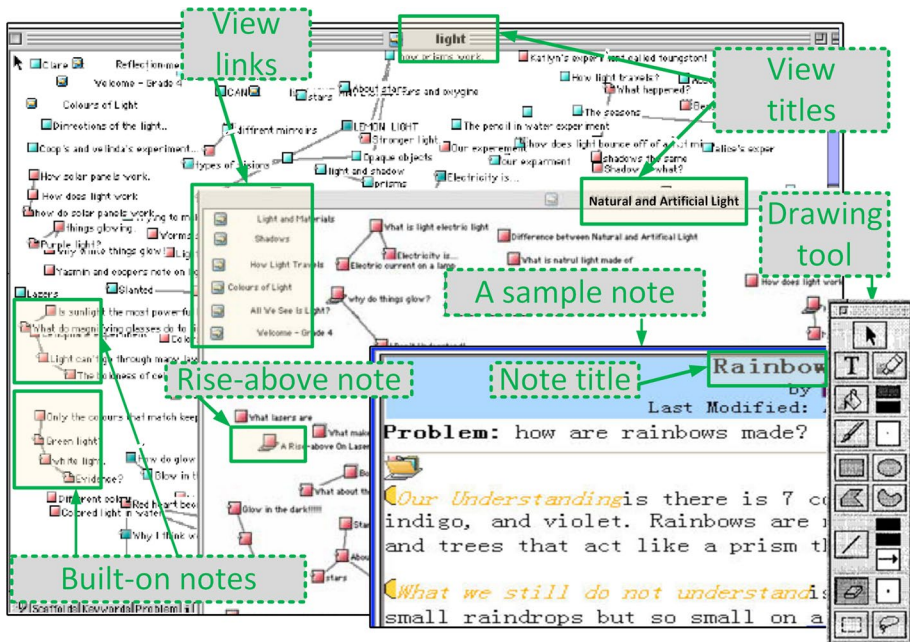
Fig. 1 Screenshots of Two Knowledge Forum Views (Background "Light"), Middle Image ("Natural and Artificial Light") with Features Indicated; the Note in the Foreground Shows a Student-Produced Text Note Using Scaffolds

typically combining these media or writing without any drawings (i.e., a non-graphical note). They simply choose the representational medium best suited to the expression of their ideas, with no required pattern of use.

With the help of Knowledge Forum, students became aware of each other's contributions through conversation and reading each other's notes, thus as mentioned above, students have an audience for their ideas and are positioned to assume collective responsibility for communicating, elaborating, evaluating, and improving ideas through reading, building on, and citing. In many ways they help to advance each other's understanding, through peer feedback, co-authorship, and opportunities to revise ideas and graphics.

The teacher encourages—and provides time for—students to (1) read all the notes in the Knowledge Forum view for which they were responsible, (2) summarize the problems of their current inquiry, (3) elaborate what they do not yet know and need to know, (4) advance ideas/theories/hypotheses and refine them as they proceed, adding resources and relevant information. In addition to working in their own views they are given time and encouraged to read work in other views, contributing ideas from their area of specialization and evaluating and improving class ideas and engaging in opportunistic collaboration, re-grouping as needed to address emergent ideas for collective knowledge advancement, rather than remain in fixed-groups to complete pre-planned activities. Rotating leadership has been shown in Knowledge Building classes as early as Grade 1 (Ma et al., 2017).

With Knowledge Forum integral to students' work, it serves not only as a communal space for collaborative knowledge building through online writing and drawing but also

provides a record of students' idea improvement and collaboration, as well as providing a flexible framework for idea-centered discussion within and between groups based on evolving ideas.

Data collection and analysis

The dataset collected to address our research questions consisted of 332 *notes* in eight different Views in the Knowledge Forum database produced by the fourth-grade class (see Appendix Fig. 11 for details). The procedure for analyzing notes in Knowledge Forum was as follows. First, the textual content of notes was analyzed along four dimensions: number of words, number of sentences, number of idea units, and overall idea quality. The rationale for four different measures was to capture indicators of writing and idea production. Number of words and the number of sentences provide two basic quantitative indicators of writing production. However, as ideas are not completely stored in human memory in a sentence form (e.g., Anderson & Bower, 1973; Kintsch, 1974; Norman & Rumelhart, 1975), parsing sentences into *idea units*, using Zhang et al. (2007) coding scheme, was done before assessing the quality of ideas.

Idea unit is often defined as "a single thought unit…that conveys a single item of information extracted from a segment of content" (Budd et al, 1967, p. 34) and "the smallest unit of text that conveyed a distinct idea…in student's note in Knowledge Forum" (Zhang, et al., 2007, p.128). Some researchers (e.g., Anderson & Bower, 1973; Kintsch, 1974; Norman & Rumelhart, 1975) who have studied how individuals store and recall the meaning of text maintain that ideas and concepts are not stored in human memory in a sentence form but rather as idea units; that is, individuals remember ideas, not exact words in which those ideas are conveyed. Accordingly, a coding scheme (see Appendix Table 6), adapted from Zhang et al. (2007), was used to first identify the idea units in Knowledge Forum notes and then evaluate the overall quality of each idea unit. Special attention was paid to the two coding categories of idea units–theoretical (T) and factual (F)–for which drawings provided support. Then, following Chi's (1997) practical guide to quantify qualitative verbal data, each coding category, factual or theoretical, was rated based on a three-point scale. The quality ratings were then used for statistical comparisons.

Second, the quality of students' drawings and students' graphical representation skills was assessed as follows. To begin with, we applied content analysis to all students' drawings in these graphical notes according to a rubric developed to assess online drawings (Gan et al., 2010; see Appendix Table 7). In light of the rubric, each drawing was scored on a three-point quality scale, ranging from "simple" to "sophisticated," on each of the seven criteria/aspects of graphic production. Using the rubric, two evaluators worked independently to assess each drawing and the inter-rater reliability was 0.84 (Spearman correlation); differences were resolved through discussion. Based on the rating of each drawing, we calculated a composite drawing score to assess each student's graphical representation skill, with a higher score indicating better drawing skills.

Third, to answer research questions we divided the class into two groups—high-drawing and low-drawing groups (11 students in each)—based on the average number of drawings produced by each student ($M = 4.91$; $SD = 3.37$). The high-drawing group was more active in drawing with the mean drawing score of 86.70 ($SD = 43.00$), in contrast with the mean score of 25.57 ($SD = 10.31$) for the low-drawing group. After grouping, we were able to examine differences between these two groups using descriptive statistics to characterize

writing and drawing, followed by MANOVAs. We also analyzed how gender and the use of drawings were associated with the production of ideas (measured as idea units) in graphical and non-graphical notes.

Finally, samples of drawings were examined qualitatively in detail, focusing on the functions of these drawings for writing and idea development. For this analysis we adopted a conceptual framework based on DuCharme's (1991) categorization of the key functions of drawings in relation to young children's writing, including: (1) a contextual function before writing, (2) a communicative function after writing, and (3) a transitional function during writing. We provide representative drawings in the Results and Discussion section to illustrate functions served by drawings.

Results and discussion

Drawing as a tool for writing

As elaborated above, we used the following measures to assess whether children who drew more pictures demonstrated stronger writing performance: (1) number of notes, (2) number of words, (3) number of sentences, (4) number of idea units, and (5) overall idea quality. Table 1 summarizes the performance of the 22 students in graphical and non-graphical notes in terms of these variables. Each student contributed at least 7 notes and, in total, the class of 22 students produced 332 notes ($M=15.09$, $SD=6.51$). Among all the notes, there were (1) 90 graphical notes (4.09 per student; $SD=2.56$) which contained 108 drawings (see Appendix Fig. 11), and (2) 242 non-graphical notes with no drawings (11.00 per student, $SD=7.00$). The results showed that students produced more non-graphical notes than graphical notes. This came without surprise because our past experience of working with children in Knowledge Forum has shown that students produce more text-based than graphics-based notes. Contrasting graphical and non-graphical notes, on average students produced more words, more sentences, more idea units, higher quality ideas in the

Table 1 Mean scores of 22 students for graphical and non-graphical notes

Measure	Graphical notes (n=90)		Non-graphical notes (n=242)	
	M	*SD*	*M*	*SD*
Notes	4.09	2.57	11.00	7.00
Words	72.60	45.74	55.83	36.82
Sentences	4.84	4.01	3.46	2.40
Idea units per note	3.28	2.07	2.42	1.83
Overall idea quality	8.40	5.69	5.72	4.78
Factual idea units	5.36	7.59	9.41	8.49
F1 (idea units per note)	.01	.11	.06	.29
F2 (idea units per note)	.17	.50	.15	.43
F3 (idea units per note)	1.13	3.11	.64	2.05
Theoretical idea units	3.95	2.52	8.59	7.73
T1 (idea units per note)	.13	.37	.26	.56
T2 (idea units per note)	.21	.51	.23	.65
T3 (idea units per note)	.62	.98	.29	1.18

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graphical notes. The use of drawings was highly related to written text, with higher quality ratings of ideas in texts with drawings.

When the analysis was restricted to graphical notes, we found that the high-drawing group produced on average 7.45 drawings ($SD = 2.94$) distributed across a mean of 6.05 graphical notes ($SD = 2.09$) whereas the low-drawing group produced a mean of 2.36 drawings ($SD = 1.01$) distributed across a mean of 2.14 graphical notes ($SD = 1.03$). Table 2 shows that the high-drawing group also produced more words ($M = 77.67$ vs. $M = 67.53$), more sentences ($M = 5.72$ vs. $M = 3.95$), more idea units ($M = 3.69$ vs. $M = 2.86$), and much higher quality ideas ($M = 52.12$ vs. $M = 13.79$). The drawings produced by the high-drawing group were also much more sophisticated ($M = 86.70$ vs. $M = 25.57$).

Drawing as a means of refining ideas

To address the second research question regarding the association between drawing and idea improvement, we conducted a multivariate analysis of variance (MANOVA) to examine group (low- vs. high-drawing groups) and types of notes (graphical vs. non-graphical) as two independent variables (IVs) and the five idea-improvement measures as the dependent variables (DVs). To start, it was found that Levene's homogeneity of variance assumption was fulfilled for the variables related to the non-graphical notes (all p's > 0.05), but was not fulfilled for the variables related to the graphical notes (all p's < 0.05). Allen and Bennett (2008) suggested that if homogeneity of variance cannot be assumed for all the dependent variables, it is needed to adopt a α-level stricter than 0.05. (e.g., 0.01). So, for this specific test we set our α-level at 0.005. As shown in Table 3, it was found that in the case of graphical notes, there were significant group differences with respect to all five dependent variables (Wilks *Lambda* = 0.305; $F(5, 16) = 7.304$, $p = 0.001$, partial *eta square* = 0.695); but in the case of non-graphical notes, there were no group differences with respect to the four applicable measures (drawing scores were not applicable for non-graphical notes) (Wilks *Lambda* = 0.828; $F(4, 17) = 0.882$, $p = 0.495$, partial *eta square* = 0.172). Results suggest that drawing played an important role in students' knowledge building, especially with respect to idea production and improvement.

We further analyzed two types of idea units (factual and theoretical) in all graphical and non-graphical notes. Figure 2 illustrates the distribution of ideas of three different quality levels; the percentages are reported for each of the 2×2 categories: factual

Table 2 Mean scores of the low- and high-drawing groups for graphical notes	Measure	Low-drawing group (n = 11)		High-drawing group (n = 11)	
		M	*SD*	*M*	*SD*
	Notes	14.27	6.32	15.91	6.90
	Words	67.53	27.89	77.66	59.66
	Sentences	3.95	1.47	5.72	5.46
	Idea units per note	2.86	0.99	3.69	2.77
	Overall idea quality	13.79	4.89	52.12	34.11
	Drawing score	25.57	10.31	86.70	43.00

Table 3 *F*-values for comparisons of the two groups' performance in graphical and non-graphical notes to determine if drawing is positively associated with idea improvement

Measure	Graphical notes				Non-graphical notes			
	df	*F*	p	Partial η^2	df	*F*	p	Partial η^2
Words	1	14.451**	<.001	.419	1	1.198	.287	.057
Sentences	1	9.729**	<.005	.327	1	.831	.373	.040
Idea units	1	15.909***	<.001	.443	1	1.140	.298	.054
Overall idea quality	1	13.615***	<.001	.405	1	1.523	.232	.071
Drawing score	1	21.030***	<.000	.513	–	–	–	–

**p < .005

***p < .001

Fig. 2 Percentages of the theoretical and factual idea units with varied levels of sophistication (T1-T3 and F1-F3) in graphical and non-graphical notes
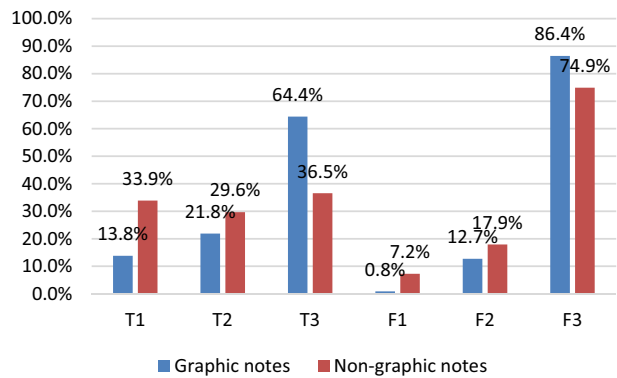
vs. theoretical ideas in graphical vs. non-graphical notes (see Appendix Table 6). As shown in Fig. 2, the quality of factual idea units only slightly favored graphical notes, indicating a weaker linkage between drawings and children's grasp of scientific facts. There were, however, larger differences for theoretical idea units between the graphical notes and non-graphical notes, with comparatively more scientific idea units found in graphical notes. Specifically, as shown in Fig. 2, all levels of theoretical idea units were similarly represented in children's non-graphical notes (T1 = 33.9%; T2 = 29.6%; T3 = 36.5%) whereas in graphical notes a much higher percentage of idea units were scientifically sophisticated (T1 = 13.8%; T2 = 21.8%; T3 = 64.4%). A Spearman correlation analysis further uncovered a strong positive correlation between the overall quality of student ideas and their drawing score (Spearman's *r* = 0.86, *p* < 0.001, two-tailed). These findings indicated a positive association between drawing and conceptual understanding in the knowledge building class.

Gender differences

The third research question was concerned with gender differences in drawing, writing, and idea improvement. As shown in Table 4, there were no gender differences in writing or drawing performance in graphical and non-graphical notes. We also looked at the

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Table 4 F-values for comparison of boys' and girls' performance in the graphical and non-graphical notes

Measure	Graphical notes			Non-graphical notes		
	df	F	p	df	F	p
Words	1	.008	.931	1	1.457	.242
Sentences	1	.039	.846	1	1.547	.228
Idea units	1	.066	.799	1	1.869	.187
Overall idea quality	1	.022	.883	1	1.759	.200
Drawing score	1	.605	.446	–	–	–

Table 5 F-values for the gender by drawing group interaction with respect to writing and drawing performance in graphical and non-graphical notes

Measure	Graphical notes			Non-graphical notes		
	df	F	p	df	F	p
Words	1	2.355	.142	1	2.004	.174
Sentences	1	1.353	.260	1	2.128	.160
Idea units	1	1.150	.298	1	0.914	.352
Overall idea quality	1	1.006	.329	1	0.736	.402

interaction between gender and drawing group in graphical and non-graphical notes but found no interaction effects with respect to either writing or drawing performance (see Table 5).

Functions of drawing in relation to idea production and writing

Young children may use one drawing to serve one or multiple functions including (1) a contextual function before writing, (2) a communicative function after writing, and (3) a transitional function during writing (DuCharme, 1991). Applying this conceptual framework, we analyzed the use of drawings in specific discourse contexts and report representative examples of children's drawings below. This qualitative inquiry would help us interpret positive associations between drawing and idea improvement reported above.

Contextual functions for idea generation and writing

Labeling objects to aid communication Drawing provided students a medium to label various objects. Using labels students could identify an object or the nature of a process of interest to an ongoing inquiry. Integrative use of labels and longer text helped to make students' graphical notes more accessible to their peers. Figure 3 presents a graphical note authored by a student. This note contained a drawing and an accompanying piece of text. This student used words to label the various objects used in an experiment and described the experiments in the text body of the note.
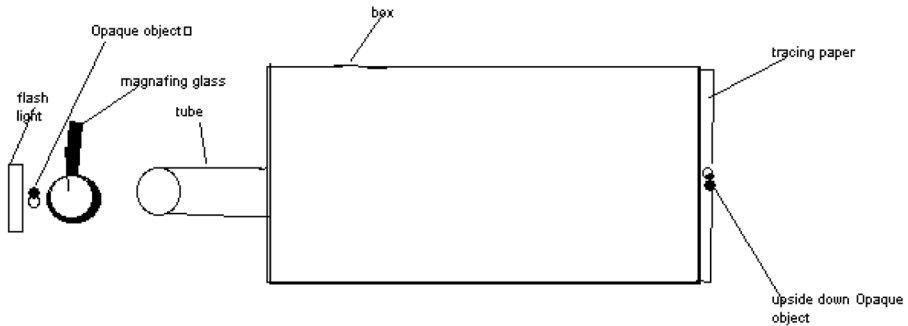
Fig. 3 A graphical note illustrating the labeling of objects. [Note Title: upside down pictures] [Problem: How can you see upside down pictures?] by Y.B. Note Text: Cut off one side of a box. Then on the other side stick a tube threw [through] it. Put a magfining [magnifying] glass over the tube. Then put a sheet of tracing paper over the side you cut out. Then shine a flash light on a[n] opaque object. Look at the tracing paper. We saw that the opaque object turned into light and went upside down
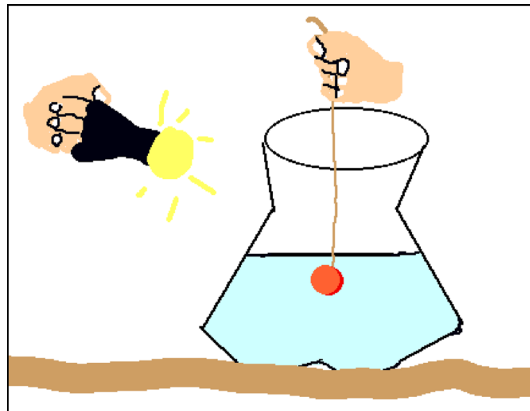

Fig. 4 A graphical note illustrating use of drawing to record an experiment. [Problem: The closer you see it, the deeper it is.] by M.S., E.O. and V.M. Note Text: E.O., V.M. and M.P. did an experiment on Bending light. The way you do this experiment is put a peice [piece] of clay on a thin string and put it in a jug of water. Then shine a flashlight on the peice [piece] of clay you put in the water and look through the top of the jug. Doas [does] the object look closer? Now look under the water where the peice [piece] of clay is. The object looks closer to you when you look down into the water

Recording experimental processes or experiences In many cases, children's drawings provided graphical representations of experiments, personal experience, or observations. As part of their study of optics students drew many pictures to illustrate observations from experiments and field trips. Their drawings contained detailed illustrations of the experiment results which were also described in the note text. For example, one graphical note coauthored by M.S., E.O. and V.M. did not use any labels but provided an illustration of an experiment on bending light (see Fig. 4). The text body described the experiment process and reported these students' observation: "The object looks closer to you when you look down into the water."
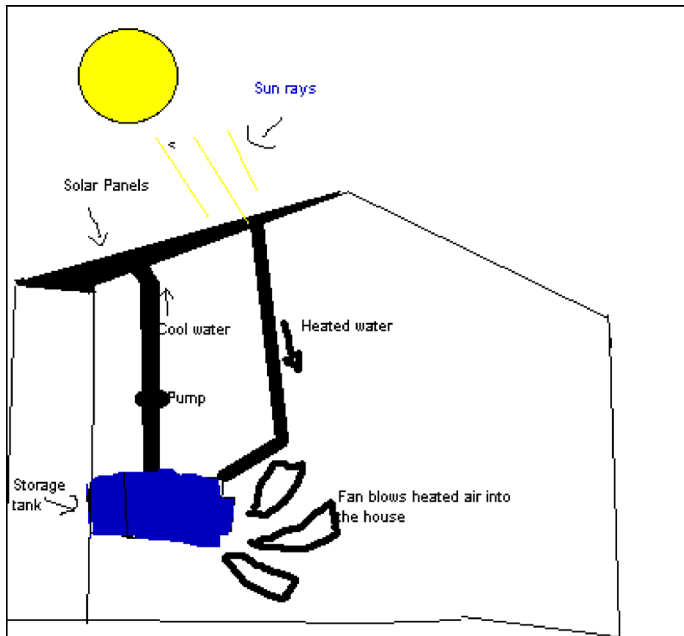
Fig. 5 A graphical note example of using drawing to describe the working process of a device. [Problem: How solar panels work?] by W.L., D.B. Note Text: We read a reading and here is a diagram of what we learned and how solar panels work. [New information] (Italicized text enclosed in square brackets is a Knowledge Forum "scaffold".) Dull dark surfaces do not reflect much light so they are perfect for solar panels. Instead they absorb the sun's rays and turn them into thermal energy. This means that on a roof there are dark hoses of water. The water heats up because the hoses are absorbing the sun's rays and they are insulated. The heated water is pumped into a storage tank where it used to heat the house

Describing mechanisms and processes Drawing has an advantage over writing when it comes to detailing how a device works or how a phenomenon unfolds. Drawings as such provide visible support for written description of complex sequential procedures. Take Fig. 5 for example. This drawing is focused on illustrating the process of turning solar energy into thermal energy; while it uses labels as well, the emphasis is on explaining how solar panels work by combining the drawing with the explanatory text.

Representing a theory or a concept Visualizations such as drawings, pictures, and schematics play important roles in building models and presenting theories and concepts (Klemm & Iding, 1997). Drawing can be used to explore abstract concepts, build models, and explain theories. In many cases, young students drew diagrams to depict what they understood or imagined, supporting ongoing theorizing in the class. For example, when trying to understand how light travels, a student M.R. came up with a "Tube Theory" that posited light to travel "in a tube or cylinder with wave in a criss-cross pattern" (see Fig. 6). With the graphical illustration, the note's text body added further details to reconcile the conflict between the straight travel path and the wave theory of light.
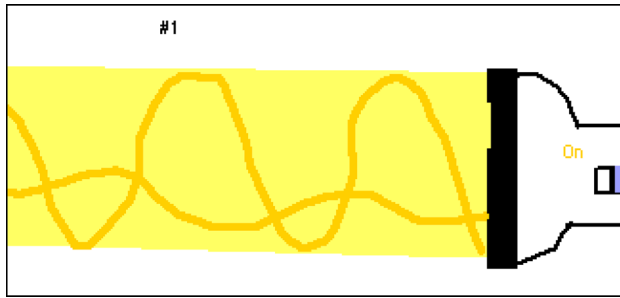
     ⁂ Springer

Fig. 6 A graphical note illustrating the use of drawing to represent a theory or a concept. [Note Title: Does light travel in a Mix?][Problem: Does light travels in a tube, a combination of straight line and waves?] by M.S. Note Text: [My theory] is called the Tube Theory. I think that Light travels in a tube or cylinder with wave in a criss-cross pattern. Because light appears to be travelling in a line, but waves could be inside the tube, but also the waves inside could bend the lines when light travels through a prism. We see light travelling in a straight line because our eyes cannot see the waves in the tube
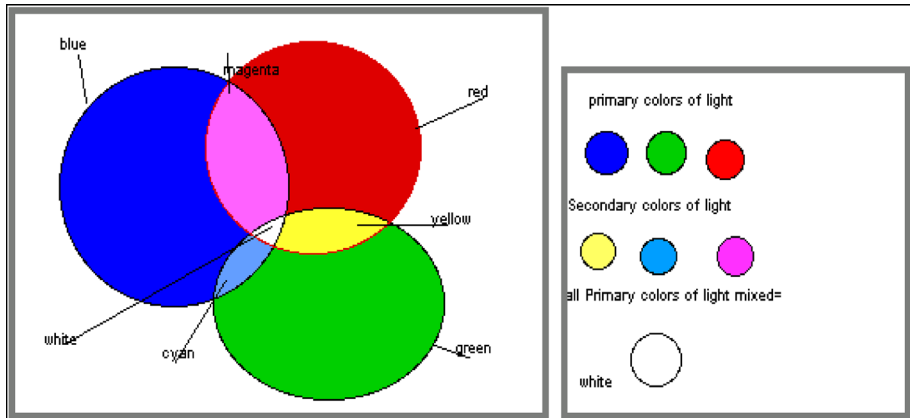
Fig. 7 A graphical note illustrating the use of drawing for clarification. [Title: The colors of light] by C.R., Y.B. [It's a rise-above note.] Note Text: [Our Understanding] Me and C.R. think that the primary colors of light are red, blue and green and when they are mixed together they make the secondary colors of light and the primary colors mixed altogether they make white light. J.E. thinks that red, blue and yellow are regular primary colors and blue, green and red are the primary colors of light.E.O., J.C. and R.D. think the same way as we do. M.S. thinks that Red, green and yellow are the primary colors of light. [What we still do not understand] What happens when the secondary colors of light mix together, will they make white light? (Color figure online)

Communicative functions for idea generation and writing

Clarification Children used drawings to clarify written ideas or information they read and to communicate meanings with each other. In the graphical note reproduced in Fig. 7, two students depicted the primary colors (red, blue and green) and the secondary colors (yellow, cyan and magenta) of light. Students who didn't know what the secondary colors of light were could directly see them in the drawing. The two students who made this note also demonstrated cohesive writing as they synthesized similar ideas together into a "rise above" note. Their statement on "what we still do not understand" indicated their recognition of
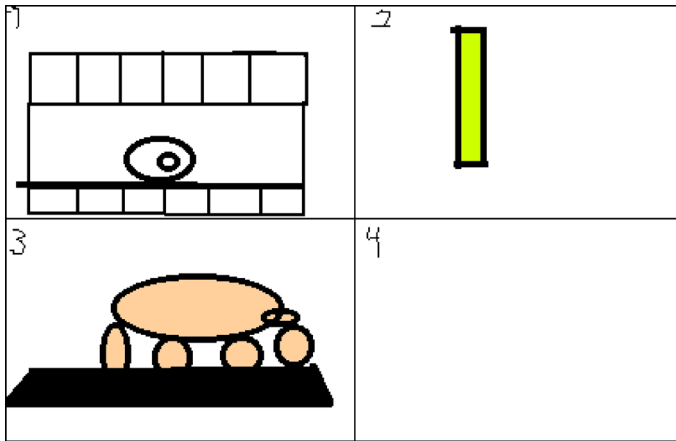
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Fig. 8 A graphical note with examples of using drawing for illustration. [Problem: What is luminescence?] by M.S., N.B., N.U., V.M. Note Text: [New information] #1 Triboluminescence is different sourses [sources] that glow by friction and can create blue sparks. One of these sour[c]es is winter-green "Life Savers." If you are chewing one, turn the lights off. Look in a mirror while chewing. Look in your mouth and you will see the candy brakes [breaks] up…. #2 Chemiluminescence is produced by certain chemical reactions. For example: glow sticks. #3 Electroluminescence is produced by electric discharges. For example: when silk or fur is stroked or when adhessive [adhesive] surfaces are seperated [separated]. #4 Bioluminescence is produced by a living organisms [sic.]. For example: glow worms or fireflys [fireflies] (Color figure online)

remaining gaps of understanding that required further clarification. In this case, drawings might have prompted students to recognize gaps in their knowledge or to pose new questions leading to further inquiry.

Illustration Drawing is commonly used in science to illustrate ideas. In this study, illustrations helped students communicate ideas. For example, Fig. 8 shows a note co-authored by four students to explain different types of triboluminescence; they created these drawings to illustrate and communicate current information to their peers.

Fig. 9 A graphical note as an example of using drawing for decoration. [Problem: why does light bounce?] by Y.B., C.Q. Note Text: [My problem of understanding] Why does light bounce of a mirror with tissue paper on it and without it. Me and C.Q. think it is because of the mirrors. We could be wrong!

Decoration Occasionally children would draw a picture for aesthetic reasons; that is, the drawing was more elaborate than what was functionally necessary, containing additional elements for decoration. Although decorative elaboration has questionable benefit for written idea production, it could possibly facilitate student engagement and imagination and made both drawing and writing more enjoyable. Take Fig. 9 for example. At first it appeared that decorative elaboration (such as these two human figures) was not related to the writing at all. However, the drawing along with an aesthetic appeal also provided a context for more written production, as well as a sense of entertainment.

Transitional functions for idea generation and writing

Drawing can serve as a springboard for children to convey ideas in text by using objects, lines, and colorful dots (see Fig. 10). Results suggest that drawing helped them develop and organize ideas, with benefits for written communication.

Conclusions and implications

A mixed-methods case study was used to explore the association between idea-centred drawing and idea-centered writing in a Knowledge Building classroom. The main findings can be summarized as follows. First, the high-drawing group outperformed the low-drawing group in terms of four note-writing measures (i.e., number of words, number of sentences, number of idea units, and overall idea quality), but performed similarly in the non-graphical notes. Samples of fourth-grade student work are presented to illustrate ways in which drawing and writing in combination helped students produce and improve ideas.
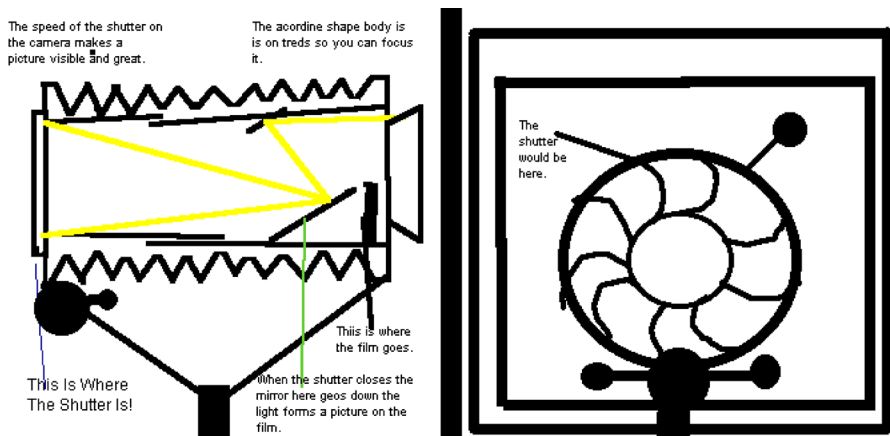

Fig. 10 An example graphical note of using drawing for transitional function. [Title/Problem: What is the speed of the shutter?]: C.Q., C.L.K. The speed of the shutter on the camera makes a picture visible and great. The shutter if it's too slow can let in too much light, so the picture turns white. If the shutter is too fast it will make the picture turn out black. When the shutter closes with light a mirror in behind it will go down making the picture will illuminate and the picture last seen will turn out on the film. If there is a lot of light then you want the shutter small so too much light does not get in. If there isn't a lot of light then you want it open a lot so you can see the picture

Second, data showed that drawing was associated not only with higher productivity in writing but also idea improvement and refined understanding of problems. Accounts of ways in which drawings helped students enrich and deepen thinking, combined with the positive correlation between ratings of drawings and idea improvement, suggest positive effects may extend to other subject areas and contexts.

Third, there were no gender differences in writing and drawing performance, nor interaction between gender and the use of drawings with respect to writing performance. Drawing was positively associated with both boys' and girls' idea production and writing in the knowledge-building classroom. Both girls and boys were more productive writers when they produced drawings. As boys usually lag behind girls in terms of writing development (Silberman, 1989), it is possible that drawing was especially beneficial in supporting boys' writing.

The student drawings analyzed in this study were found to serve multiple functions—contextual, communicative, and transitional—identified by DuCharme (1991). Drawing seemingly helped students elaborate the problem context (Mavers, 2011), exchange diverse ideas (Galbraith, 2009; Van den Bergh & Rijlaarsdam, 2007), and integrate ideas into coherent mental models (Wright, 2010).

Writing consists of planning, translating ideas to text, reviewing and revising, and drawing appears to interact productively with each, supporting more comprehensive or holistic planning, possibly because students "hold" thoughts in external, graphical form rather than in working memory, and with ideas accessible throughout note production there is more systematic analysis, restructuring, and production of new connections (Caldwell & Moore, 1991; Halperin et al, 2013; Mavers, 2011). Overall, organizing ideas in graphic form appears to highlight interrelationships between ideas, with ideas of greater significance and worth more evident (Chen, 2017). Drawing may accordingly facilitate exploration of a large quantity of ideas so the most promising ones can be selected, facilitating more organized presentation.

The boy-girl comparison findings can only suggest the prospect of closing the gender gap in writing performance. Nonetheless, there is suggestion that a multimedia environment with integrated use of drawing and writing was helpful in supporting boys in production of higher quality notes than they would have produced using text alone.

Overall, our findings are consistent with conjectures by scholars regarding the positive value of drawing as generative learning (Fiorella & Mayer, 2015, 2016; Leutner & Schmeck, 2014; Wittrock, 1992) and important in science understanding (Ainsworth et al., 2011). Findings also support prior research on the use of educational technology and computer assisted multimedia (i.e., pictures and text) to facilitate learning (e.g., see Mayer, 2017; Herrlinger et al., 2017). Mayer's (2017) theory on multimedia for learning posits that students can learn better and more deeply from a combination of text (words) and graphics (pictures) than from text (words) alone. Our findings add fresh perspective regarding diversely represented ideas leading to their improvement and consequent stronger writing.

Previous research has shown that preliminary drawings can enhance young students' writing by acting as a scaffold for idea generation and word selection (Bissex, 1980; Calkins, 1986). The current finding that both the high- and low-drawing groups showed better writing performance in their graphical notes, in contrast to their non-graphical notes, supports the idea of drawing as a scaffold for planning through external representations and revision.

The study raises a number of issues for future research. Knowledge Building provides a broad educational framework within which the complementary effects of drawing and writing have been demonstrated. The study itself represents a single case that may not be

generalizable to other settings (Steffe & Thompson, 2000). The participants already had one-year experience with Knowledge Building, class size was small, the teacher encouraged students' idea-centered drawings and text, and the class as a whole provided social and technological support for contributing to community knowledge; indeed, the setting might be considered optimal for idea-centered drawing and writing and not easily replicable. Further investigation might isolate contributing factors to assess independent influence and causal relations. However, from an educational perspective, a higher priority is seemingly replication in different contexts. Fischer and Bidell (1997) argue for the power of starting with what young learners are able to do under optimal conditions, to set the stage for what is possible. Follow-up research can then be conducted across diverse settings. The current study was in the area of science—would it hold in other subject areas, with a different multimedia environment, at different grade levels, with a different teacher, with a different pedagogical model? Could results be strengthened? If so, under what conditions? With multimedia environments increasingly embedded in education and the importance of graphical literacy arguably more important than ever, understanding ways to support the reciprocal and powerful interaction of idea-centered drawing and writing seems the most pressing challenge arising from this research.

Other issues for further investigation relate to causal relationships between drawing and writing and knowledge advancement. Idea units are stored and processed in human memory (Maki & Swett, 1987). It may be interesting to examine whether producing text (words) before producing drawings (graphics) or the reverse has an effect on the quality of ideas. Also, the present study only illustrates potential functions of drawing associated with idea production in writing; future studies may include in-depth qualitative analysis to examine how drawing types, drawing preferences, and distribution of drawings etc., are related with idea production and written communication.

Practical pedagogical implications of this study point to the importance of graphical representation of ideas and idea-centered writing integral to knowledge work—would such findings be found across the curriculum? Technologically, drawing tools should support graphical literacy, as suggested in this paper, favoring tools and e-learning platforms that support multimedia. Teacher education and development programs might well provide opportunities for pre-service and in-service teachers to develop interdisciplinary, multliteracy teaching knowledge and skills.

Knowledge Building has been shown to improve literacy (Sun et al, 2010; Pelletier et al., 2006; Scardamalia & Bereiter, 2003). The graphical tools in Knowledge Forum support graphical literacy, complemented by written accounts that enable the sharing and communication of ideas improved in light of diverse input and feedback from peers. This provides a context for discourse that is meaningful and integral to day-to-day work; distributed expertise, with community members committed to helping each other provides peer support for use of new media and idea improvement (see also Chen & Hong, 2016; Scardamalia & Bereiter, 2014). This study suggests that sustained, collective Knowledge Building in Knowledge Forum engages young children in productive graphical and textual literacy.
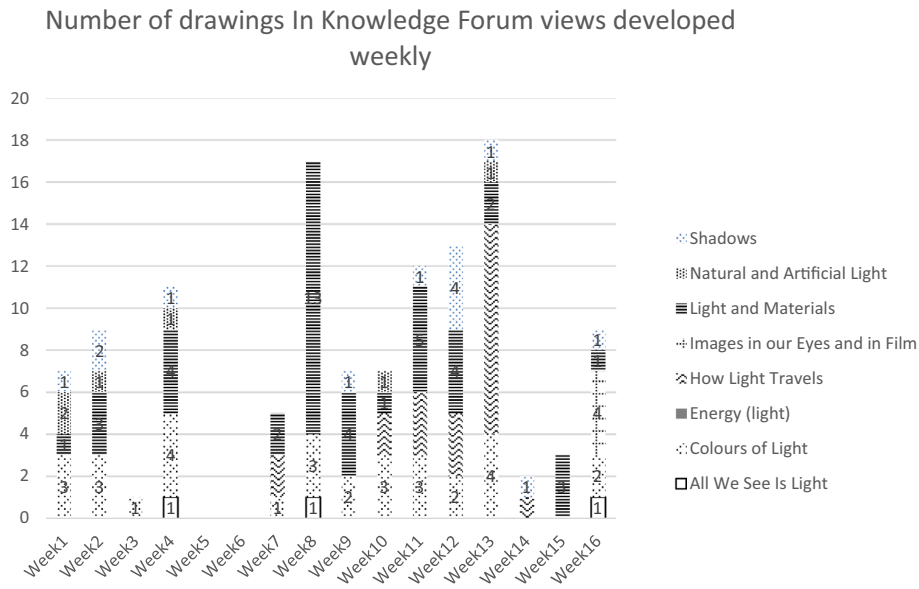
Appendix 1

See Fig. 11.

Number of drawings In Knowledge Forum views developed weekly

Fig. 11 Number of drawings in Knowledge Forum views developed weekly

Appendix 2

See Table 6.

Table 6 Coding framework for content analysis of idea units

Categories	Sub-categories and defining features	Examples
Theoretical/conceptual idea	The scientificness of conceptual idea units: *Pre-scientific (T1):* conceptions, theories and explanations are misconceptions based on naive conceptual framework *Hybrid or mixed (T2):* Misconceptions that have incorporated scientific information or concepts and ideas based on scientific framework but not precisely scientific *Scientific (T3):* Explanations, conceptions and theories are consistent with scientific knowledge	(T1): [Title: colored light in water.] [My theory] when plain light goes through water, the water takes a bit of the shine of the light. But when colored light goes through water, the water takes a bit of shine and color from the light (T2): [Title: Only the colours that match keep going.][My theory] is that when light hits a thing that's green only the green part of the light keeps going and the rest of the light that is not green fades way because it is not used because those parts are not green (T3): [Title: my theory that light travels in a straight line but it is a wave.]I agree with you because my theory is that light travels in a straight line but it is a wave. Light is made up of the electromagnetic waves
Factual idea	The truthfulness of factual ideas units: *Unelaborated (F1):* Facts, experimental results, experiences, or observations are without careful elaboration, not consistent with scientific truth *Hybrid or mixed (F2):* Those are part of scientific truth with some mistakes, not completely consistent with scientific truth *Elaborated (F3):* Those are scientific truth, completely consistent with scientific truth	(F1): [Title: coloured light.]I found that if you shine light on a waxed mirror it doesn't reflect, but with colored light it does (F2): [Title: Big and small shadows.] A shadow is always attached to the opaque object that formed it. There is only a shadow when there is light all around you (F3): [Title; what is a shadow?] [New information] shadow = a darkness made when light shines on to a[n] opaque (non-transparent) thing…

Appendix 3

See Table 7.

Table 7 Coding framework for drawing rubric

Categories	Description	Score		
		Low	Mid	High
Graphic production skills	Basic computer drawing tools are used effectively, with combined and sophisticated use of lines, dots, shapes, colors, simple labels and titles	1	2	3
Graphical representation of ideas	Drawings are used to enhance information in the text notes accompanying the graphics students produce. Low scores were assigned when students' drawings had nothing to do with the text or were not finished. Higher scores were assigned when students' drawings were helpful in providing concrete grounding for abstract concepts, experiments, theories, etc., or in other ways served to clarify ideas in accompanying texts	1	2	3
Source information	References convey source information (i.e., information from the Internet, text, personal communication) used in the production of the graphic. Higher ratings were associated with more detailed and adequate accounts of source material and full bibliographic information	1	2	3
Captions	Labels and other text elements are added to the graphic to complement, explain, elaborate, or summarize ideas conveyed in the graphic. Higher scores were given to captions that clearly and accurately conveyed ideas in graphics	1	2	3
Revisions	Graphics are revised, as reflected in log files that track changes over time, to convey ideas more effectively. Higher scores were given to more frequently revised and reworked graphics	1	2	3
Aesthetics	Advanced drawing tools (e.g., layers) and graphic displays are used to improve the clarity and effect of a graphic. Scores were based on a qualitative or impressionistic rating of the attractiveness of the graphic as a whole, including harmony of different parts and efforts to create special effects	1	2	3
Interpretive summaries and reflections	Summary statements were added to graphical representations to achieve text-graphic integration that then resulted in a higher-level account than judged possible with text or graphics alone. Correspondences between student graphics and accompanying text were analyzed to determine the extent to which the graphics and text complemented each other, thereby resulting in a higher-order account of their conceptual content. For example, one highly rated graphical note summarized a great deal of text the students had generated, presenting an account through use of five graphical panes corresponding to five theories on how light travels	1	2	3

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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