Early Development of Graphical Literacy through Knowledge Building

Le développement de la littératie graphique à travers la coélaboration de connaissances

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Abstract

This study examined growth in graphical literacy for students contributing to an online, multimedia, communal environment as they advanced their understanding of biology, history and optics. Their science and history studies started early in Grade 3 and continued to the end of Grade 4; students did not receive instruction in graphics production, nor were they required to produce graphics. Results show that students spontaneously produced graphics that advanced along seven dimensions, including effective representation of complex ideas, use of source information and captions, and aesthetic quality. On average, the scores for the seven dimensions were higher for Grade 4 students with two years of experience with Knowledge Building pedagogy and technology (Knowledge Forum®) than for Grade 6 students with one year of experience. The overall pattern of results suggests reciprocal enhancement of graphical, textual, digital, and scientific literacy, with students exceeding expectations by available norms, and performance enhanced through extended Knowledge Building experience.

Résumé

Cette étude examinait la progression de la littératie graphique d'élèves participant à un environnement multimédia collaboratif en ligne au fur et à mesure que s'améliorait leur compréhension de la biologie, de l'histoire et de l'optique. Les études en sciences et en histoire de ces élèves ont commencé au début de la troisième année et ont continué jusqu'à la fin de la quatrième année. Les élèves n'ont pas reçu de directives sur la production de graphiques et n'étaient pas non plus tenus de produire des graphiques. Les résultats démontrent que les élèves ont spontanément créé des graphiques qui tendaient vers sept dimensions, incluaient une représentation d'idées complexes, utilisaient des sources d'information et des légendes et portaient une attention à la qualité esthétique de l'ensemble. En moyenne, les notes pour les sept dimensions étaient supérieures pour les élèves de quatrième année avec deux ans d'expérience avec la pédagogie et la technologie (Knowledge Forum) en coélaboration de connaissances, comparativement aux élèves de sixième année avec une année d'expérience. Les résultats généraux suggèrent une amélioration de la littératie graphique, textuelle, numérique et scientifique, les élèves dépassant les exigences selon les normes disponibles, ainsi qu'une performance améliorée par une expérience de coélaboration de connaissances accrue.

Introduction

Images can convey complex meaning, as suggested by the proverb, "a picture is worth a thousand words." The ability to produce and interpret visual and graphical representations is important for effective participation in a multiliterate, digital-age society in which information and communication technologies transform ways of reading, writing, speaking and listening (Leu, Kinzer, Coiro & Cammack, 2004). Graphical literacy is crucial for obtaining information, constructing knowledge, and successful learning (Bamford, 2003) and involves a complex interplay of multiple sign systems, modalities, and communicative and cognitive processes (Hill, 2006).

Graphical literacy involves a range of visual thinking and communication skills (Jolliffe, 1991) and the ability to use graphic tools to construct, present, read, and interpret charts, maps, graphs, and other visual presentations (e.g., spreadsheets, timelines, cartoons, photographs) that supplement prose in textbooks, nonfiction trade-books, and newspapers (Readence, Bean & Baldwin, 2004). Visual thinking is defined as processing information through images or graphics instead of words (Olson, 1992) and graphical representations help support and externalize visual thinking, aiding creative problem solving and intellectual development. Visual thinking is a fundamental and unique part of our perceptual system aiding in the construction of mental models that can lead to productive thinking and learning (West, 1997) and supporting verbal and symbolic forms of expression (McLoughlin & Krakowski, 2001). Aristotle stated that, "without image, thinking is impossible" (as cited in Benson, 1997, p. 141). Barry (1997) suggested that non-linear visual thinking has creative power and taps natural intelligence, playing an important role in advancement of scientific understanding (Earnshaw & Wiseman, 1992; Peltzer, 1988) and creative thinking (De Bono, 1995; Torrance & Safter, 1999).

A growing literature suggests graphical literacy is as important as textual literacy. However current learning theories underplay this important dimension of development and there is little to guide work at the elementary school level. Further, graphical literacy is largely ignored in school texts (Readence, et al., 2004). Some feel that visual thinking and representation are learned from direct experience and that they do not need to be taught while others argue that higher order visual literacy skills do not develop unless they are identified and explicitly taught (see, for example, Avgerinou & Ericson, 1997; Bamford, 2003). Educational researchers are calling for increased attention to graphical inscriptions to aid production and interpretation of abstract concepts (Roth, 2002).

Although articles on graphical representation highlight the importance of visual literacy, drawing, illustration and so forth, only a few guidelines for assessing growth are available. Researchers on children's art (Cox, 1993; Harris, 1963; Krampen, 1991; Lasky & Mukerji, 1980; Melzi, 1967) refer to developmental stages of drawing. Krampen suggests the following four states: Scribbling (age 2-3); Fortuitous and Failed Realism (age 3-5); Intellectual Realism (age 5-8); and Visual Realism (age 8-12), with the latter referring to children's ability to draw what they actually see. Seefeldt (1999) stresses that children's drawing is representative of general cognitive and concept development, "not simple maturational development"(p. 205) and some argue that children produce drawings from what they know more than from what they see (see, for example, Piaget & Inhelder, 1956). While the literature on development of drawing informs developmental accounts of graphical literacy, new media for representing ideas greatly expands the issues and concepts to be dealt with. Overall, there are few accepted principles and methods for assessing growth in graphical literacy—in stark contrast to the assessment of growth in reading and writing. In part this is due to the fact that graphical representations are difficult to score reliably (White & Gunstone, 1992).

Development of Graphical Literacy Across Content Areas

Felder and Soloman (2001) note that most people are visual learners, suggesting that the inclusion of visual content in learning material will promote deeper processing and retention of information, regardless of content area. Graphical and visual forms of representation can offer advantages over text when conveying abstract concepts and spatial and proportional relationships within and between objects, and thereby facilitate understanding of information and data (Tufte, 1997). Further, attention to graphical literacy across content areas can help students understand both graphics and conceptual content (Bamford, 2003; Jolliffe, 1991), and young learners can use graphics to construct meaningful concept representations and visualizations to enhance learning (Bliss, Askew & Macrae, 1996).

Working with visual and spatial representations has long been a topic in cognitive studies (Schwartz & Heiser, 2006). Although mostly conducted in laboratory settings, these studies suggest important principles for incorporating graphical literacy across content areas.

(a) *Dual-coding theory.* This theory provides accounts of graphical representation with rationale for its importance (Paivio, 1991; Rieber, 1994). First, if information is coded both verbally and visually, the chances of retrieval are increased. Second, words and graphics activate mental processing in different ways; graphics are more likely to be coded visually and verbally, whereas words are far less likely to be coded visually.

(b) *Multimedia principle.* Clark and Mayer (2002) compared learning about various mechanical and scientific processes, including how a bicycle pump works and how lightning forms, from lessons that used words alone versus those that combined words and graphics (still graphics and animations). Their research indicates that graphics plus text can facilitate learning by helping learners construct mental models that are essential for comprehending the information to be learned and, in turn, increasing retrieval of this information (Clark & Mayer, 2002). Visualization is also a powerful cognitive tool in scientific discovery and invention, and essential to problem solving in daily life as it provides concrete means to interpret abstract graphics (Rieber, 1995).

(c) *Contiguity principle.* Contiguity refers to the alignment of graphics and text in the appropriate places; placing graphics near related text can improve learning. If words and graphics are separate, the task requires extra cognitive resources to integrate them, working memory is overloaded, and learning is negatively affected. If words and graphics are placed contiguously, learning is enhanced as cognitive resources can be focused on the integration of information from multiple sources (Clark & Mayer, 2002).

The above principles highlight conditions of effective learning from graphics. We further infer that these conditions may apply to production of graphical representations of ideas. Effective communication of ideas requires proper use and integration of text, graphics, and other media forms; the alignment of multimodal representations helps learners to clarify, elaborate, and organize their ideas so that the ideas can be understood, examined, improved, and utilized by their peers. Therefore, the coding scheme and related analyses in this study examine student drawings in relation to text (e.g., captions surrounding text) and in the context of online written discourse for Knowledge Building.

Several assumptions underlie the work reported here. First, graphical literacy and deep understanding are mutually reinforcing, with graphical literacy serving as a powerful thinking tool, across content areas. Second, improvement in graphical literacy can be developed through collaborative work in which students are raising authentic problems of understanding and collaborating in an effort to advance their understanding by producing explanations that others find valuable. In this context graphics help to convey complex ideas, while input from peers provides the feedback necessary to refine and advance those ideas and the graphical representations of them.

Graphical Literacy as a By-Product of Knowledge Building

Literacy as a social practice can be best learned through dialogic communication and apprenticeship in literate discourse communities (Applebee, Langer, Nystrand, & Gamoran, 2003; Barton & Hamilton, 1998). Knowledge Building in both online and offline contexts creates diverse demands and opportunities for high-level literacy practices: extensive and cooperative reading (Scardamalia, Bereiter, Hewitt & Webb, 1996; Zhang & Sun, in press); authentic writing that integrates multimedia elements and involves real audiences (Warschauer, 2007); and continuous dialogic interactions focusing on authentic problem solving and understanding (Gan & Zhu, 2007; Applebee, 1996; Bakhtin, 1981; Cummins & Sayers, 1995; Nystrand, 1997; Swain, 2000; Zhao, Lin, Yuan & Yan, 2000).

Knowledge builders create and continually improve ideas through transformative discourse (Scardamalia & Bereiter, 1994; present issue). They take collective responsibility for communicating, elaborating, evaluating, and improving artifacts entered into a public knowledge space where all members build on and in other ways help each other advance their ideas. In this study Knowledge Forum provides the networked, multimedia knowledge space that enables this (also see Scardamalia, 2002; 2004). In the current case the basic disciplinary work was in the areas of biology, history and optics. Students chose to express their ideas using graphical or textual representations, with no requirement to use one or the other. Text notes were often used to initiate interactions, with graphics then used to extend and amplify that work. Dialogue surrounding these various inputs further supports higher order thinking and idea improvement (Mercer, 1996; Scardamalia, Bereiter, Brett, Burtis, Calhoun, & Smith Lea, 1992). This work is in line with approaches that support visual and sensory learning in technology-rich environments in which students are learning at a distance or in open-learning mode, with dynamic multimedia and telecommunications supports (McLoughlin & Krakowski, 2001; Sinatra, 1986).

Productive knowledge work is the focus for knowledge builders. To the extent that there is parallel development of multiple literacies, this occurs as a by-product of collaborative Knowledge Building in communities engaged in authentic problems of understanding and efforts to advance community knowledge (Scardamalia, 2003; Scardamalia & Bereiter, 1993). In this research we aim to demonstrate that graphical literacy is one of those by-products. Scardamalia, Bereiter and Lamon (1994) reported a study with Grade 5 and 6 students who used Knowledge Building pedagogy with Knowledge Forum (then CSILE) software integral to the operation of the classroom. Of relevance in this context was the fact that Knowledge Forum supports graphics-based workspaces (notes and views) that facilitate use of visual representations to convey higher-order cognitive processes (Lamon, Secules, Petrosino, Bransford & Goldman, 1996). The Grade 5 and 6 students in the study produced more advanced explanations and diagrams. These were associated with more causal information, with descriptions and diagrams combined to represent continental drift as a dynamic process. For example, students presented sequential frames with ordered events and arrows to convey the processes of continental drift (cited in Christal, Ferneding, Kennedy-Puthoff & Resta, 1997).

The idea that textual, dialogic, graphical, scientific, and other literacies are advanced as by-products of Knowledge Building pedagogy and technology is supported by a number of recent studies (Sun, Zhang, & Scardamalia, 2010a, 2010b; Zhang & Sun, in press) showing that students make impressive gains in understanding core content areas as well as in vocabulary, reading, inquiry, and other 21st century competencies.

Research Goals

In the current study we aim to determine if graphical literacy might also be a by-product of Knowledge Building. Toward that end the work reported provides the first developmental account of growth in graphical literacy as supported by Knowledge Building pedagogy and Knowledge Forum technology. An analytic scale consisting of seven dimensions of graphical literacy was developed and used to evaluate student work that was entered into Knowledge Forum as students worked to advance their understanding in biology, history and optics. Qualitative and quantitative assessments of graphical literacy are provided, with focus on the following research questions: (a) to what extent did the students engage and advance graphical literacy as reflected in quantitative measures of their graphic and text production in Knowledge Forum over two years (Grades 3-4)? (b) What level of improvement is evident in the quality of their graphical representations?

Method

Participants

The participants were 22 students (11 girls and 11 boys) from the University of Toronto laboratory school who studied science and social studies using Knowledge Building pedagogy and Knowledge Forum technology for two years (September, 2000 to June, 2002) in Grades 3 and 4. In Grade 3 they studied biology; in Grade 4 they studied biology, history and optics. All students were engaged in Knowledge Building and used Knowledge Forum to contribute, interpret, discuss, and advance their ideas. They also conducted experiments inside and outside the classroom. All the notes contributed were stored in Knowledge Forum and provided data for this investigation.

Because there was no control group, data were also analyzed for 22 Grade 6 students (10 girls, 12 boys) who studied science using Knowledge Building pedagogy and Knowledge Forum technology for one year. Our goal was to create comparison data to address the following questions: Would results from Grade 4 students with two years of experience compare favourably with those of Grade 6 students with one year of experience, thereby indicating that experience, not maturation alone, contribute to results?

Context: A Knowledge Building Environment

For the educational work reported in this study students were engaged in Knowledge Building through face-to-face and online Knowledge Building. As indicated above, they set forth their theories, discussed diverse ideas, conducted experiments, reported observations, elaborated on what they needed to know to advance their understanding, searched libraries and the Internet to gather and share new information, and designed research to check and improve their theories. They received no instruction in the use of graphics, but were supported in expressing ideas in graphical form through availability of an easy-to-use graphics palette that allowed them to author or co-author and revise text and graphical notes. Peers read each other's notes, commented on them, and provided various forms of feedback—and possibly helped each other learn how to use the graphics tools. We do not have records of such casual peer-to-peer interactions. What we do know is that the teacher encouraged students to operate as a community so as to take greater responsibility for their knowledge advances. Various forms of literacy were an essential part of the collective Knowledge Building process, serving the needs of communicating and improving ideas in their public, communal, multimedia space.

Data Source and Analysis

The data source for the present study was primarily students' notes in Knowledge Forum, with quantitative data and results, using Knowledge Forum's Analytic Toolkit to provide a general picture of knowledge-building practices. Qualitative analysis (Creswell, 2004) was used to examine growth in graphical literacy and to conduct content analyses (Chi, 1997) with student-generated graphics as the basic unit of analysis. The coding scheme focused on seven components of student work, in each case determining the extent to which the graphical representation makes effective use of the following.

1. Graphic production skills: basic computer drawing tools are used effectively, with combined and sophisticated use of lines, dots, shapes, colors, simple labels and titles.

2. Graphical representation of ideas: drawings are used to enhance information in text notes. 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.

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.

4. 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.

5. 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.

6. 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.

7. 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. For example, one highly rated graphical note summarized a great deal of text the students had generated, presenting an account through five graphical panes corresponding to five theories on how light travels.

Each graphic was analyzed on a 3-point scale: (1) Basic, one point, (2) Intermediate, two points, and (3) Advanced, three points. "Basic" was used to convey unelaborated and early attempts regarding various aspects of graphic production; "advanced" referred to sophisticated representations, clarity in presentation, and sophisticated use of graphics/drawing tools and accompanying text. Inter-rater reliability with 30 randomly sampled graphical representations yielded $\underline{r} = 0.84$ based on Pearson correlation, with differences resolved through discussion. Further quantitative analysis was used to examine the relationships between graphical representations and student note writing and collaboration.

Results and Discussion

Quantitative Analyses and Results

In Grade 3 students created 477 notes in eight views (e.g., Plants: Classification, Composting, Life, Survival; Worms: Classification, Composting, Life, Survival). Of the 477 notes, 65 included graphics, with three including two graphics each, for a total of 68 graphics. The average number of notes per view (text and graphics notes combined) was 59.6, with the average number of graphics per view 8.5. In Grade 4 students created 467 notes in 13 views (e.g., How Light Travels, Colors of Light, Shadows, Biomes). The average number of notes (text and graphics notes combined) per view was 35.9; the average number of graphics per view was 9.2. Altogether in Grade 4 there were 104 graphical notes with 120 graphics (13 notes included 2 or 3 graphics each). By the second year of this investigation, students were writing fewer and longer text notes. Most interestingly, from the perspective of this study, the production of graphical notes increased substantially, despite the fact that there were no classroom interventions or instructions to foster greater use of graphical representations of ideas. There was, instead, an environment with a graphics tool and community members to view and comment on student work.

Relationships between graphics, text, and collaboration as students advanced from Grades 3 to 4 were further examined.

Graphical representation and notes

Progress was evaluated through comparison of total number of graphics, and ratio of graphics to students producing notes in Grades 3 and 4. As noted above, the total number of graphics rose from 68 in Grade 3 to 120 in Grade 4. The average number of graphics per student rose from 3.09 (SD=2.32) to 5.45 (SD=3.58), with a significant change revealed through a repeated measures ANOVA (F (1, 21) = 12.27, p<0.01, η^2 =0.37). The ratio of graphics to the total number of notes rose from 14.3% to 25.7%. All but one student used more graphics in Grade 4 than in Grade 3, indicating that students were more active in Grade 4 than in Grade 3 in presenting what they had learned using graphical representations. The average number of graphics drawn by most students increased and the variation was even except for one student who had a large increase.

Graphical representation and text

The relationships between graphics and text in notes were investigated. Following the contiguity principle we might expect enhancement of learning to result from graphic-text combinations that provide a detailed account of relevant concepts. We used number of words per note with graphics as an indicator of the extent to which a student explored ideas (see, for example, Figure 3). We also considered captions or labels, and the extent to which they explained conceptual content and made the graphical representation easy for other students to understand.

The number of words per text in text-only note rose from 18.3 in Grade 3 to 49.7 in Grade 4. Most graphic notes (86.2%, Grade 3; 99.1%, Grade 4) also include text. The number of words in graphic notes with text rose from 24.7 in Grade 3 to 74.6 in Grade 4. There was a notable increase in the number of words per note—with or without graphics; the increase in the number of words in graphic notes that included text was more substantial. These textual elements were used to complement graphics and to convey complex processes such as photography, experiments (e.g., “bending-light,” Figure 2), abstract ideas (e.g., “concave and convex lenses,” Figure 3), and models (e.g., “how light travels,” Figure 5). Captions often help give meaning to graphics; accordingly, it is interesting that 41.2% of the graphics had captions or text in Grade 3 and that number increased to 54.1% in Grade 4.

Graphical representation and collaboration

Collaborative Knowledge Building fosters knowledge advancement (Scardamalia & Bereiter 1994, 1999; van Aalst, Kamimura, & Chan, 2005). An indicator of collaboration in Knowledge

Forum is co-authored notes. Two related indicators of collaborative Knowledge Building were considered: (1) the number of co-authored notes that included graphics; and (2) percentage of students co-authoring graphical notes. In Grade 3, 17.6% of graphics were co-authored, and close to half (45.5%) (n=10) of the students collaborated in the production of graphics; in Grade 4, the percentage of co-authored graphical notes increased substantially (35.0%), and all but one student (n=21) co-authored graphical notes. The results show more intensive collaboration surrounding graphical work in Grade 4 compared to that in Grade 3.

Content Analysis and Results

Growth in graphical literacy was assessed through content analysis of the 68 graphics produced in Grade 3 and the 120 graphics produced in Grade 4. These were analyzed according to the seven components of graphical literacy described previously. Figure 1 shows the results of content analyses of students' graphical representations over the two school years. The number of graphical representations rated as "Intermediate" and "Advanced" increased in five categories while the "Intermediate" level decreased in "Revisions." The four areas of greatest increase in "Advanced" ratings were "Captions," "Graphical representation of ideas," "Graphic production skills," and "Aesthetics," with corresponding decreases in the "Basic" levels in these same areas. There were not many incidents of "Source information" and no incidents of "Interpretive summaries/reflections" in Grade 3, but both appeared in Grade 4.

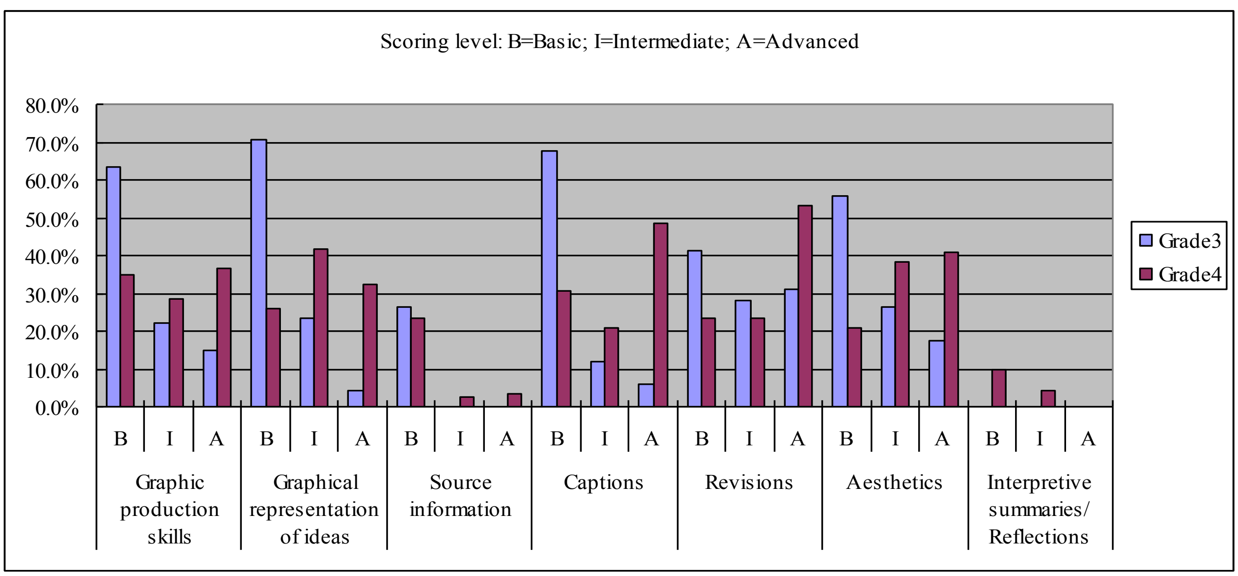

Figure 1: **Percentage of graphical notes demonstrating each of the seven different components of graphical literacy broken down according to Basic (B), Intermediate (I), or Advanced (A) levels of achievement: Grade 3 and Grade 4 Comparison.**

To enable further statistical analysis, we calculated students' average scores in the seven components (see Table 1 below) based on a 3-point scale described in the Method section (i.e., Basic = one point, Intermediate = two points, and Advanced = three points). Year-to-year differences of students' scores in each component were examined using paired t-test. Results showed a significant increase between the two school years ($t=-4.57$, $df=6$, $p<0.05$), indicating that most students made progress in the seven components from Grade 3 to 4. Nine students made progress in all seven categories. If we consider the seven components of graphical literacy and number of students out of 22 demonstrating progress on them, those numbers are 18, 19, 16, 21, 16, 17 and 15 respectively. The four areas of greatest increase in average point score from Grade 3 to Grade 4, listed from highest to lowest increase, were "Captions" (1.30), "Graphical representation of ideas" (0.88), "Aesthetics" (0.79), and "Graphic production skills" (0.68).

Table 1: ***Number and Quality of Student-Generated Graphics: Grade 3 and Grade 4 Comparisons*****.**

	Grade 3				Grade 4			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Number of Graphics	3.09	2.34	0	8.5	5.45	3.58	1	16
Quality of seven components of graphical literacy								
1. Graphic production skills	1.22	0.65	0	2.67	1.9	0.54	1	3
2. Graphical representation of ideas	1.13	0.53	0	2	2.01	0.46	1	2.91
3. Source information	0.17	0.21	0	0.67	0.42	0.26	0.1	1
4. Captions	0.95	0.61	0	2.33	2.25	0.5	1.5	3
5. Revisions	1.73	0.91	0	3	2.29	0.5	1.5	3
6. Aesthetics	1.31	0.66	0	2.33	2.1	0.54	1	3
7. Interpretive summaries/reflections	0	0	0	0	0.18	0.17	0	0.55

Note. Quality of student graphics was rated on a 3-point scale: (1) Basic = one point, (2) Intermediate = two points, and (3) Advanced = three points.

Below we review student development in each of the dimensions indicated in Table 1.

Graphic production skills

According to Anning (1999) children learn to draw and draw to learn. In this study, the ratings of student drawing skills increased from Grade 3 to 4, from an average point score of 1.22 to 1.90, (see Table 1 and Figure 1). They used more drawing elements such as color, shape, and layers, and correspondingly produced drawings with greater complexity in Grade 4. According to the developmental stages reviewed in the introduction section (e.g., Krampen, 1991), results from this study indicate that the Grade 4 students, approximate age 9, were at the fourth stage (visual realism, ages 8-12). We elaborate below in our comparison of performance between Grade 4 and Grade 6 students.

Graphical representation of ideas

Many graphical representations in Grade 3 conveyed simple, concrete objects, and seldom contained captions or labels. In comparison, in Grade 4 students' graphical notes showed more complex graphical representations of ideas such as scientific concepts, theories, working processes, and experiments. As suggested in Figure 2, two Grade 4 students conducted and visually represented results from an experiment, showing how a flame turned "flat" when observed through water and conveying in detail in a two-part drawing before-and-after images of the flame to help peers see the differences.

[**Problem:** Bending light] by: E.N., N.T.

I did an experiment on Bending Light. The flame is behind the glass. When the flame is out in the air, it looks normal. When it is next to the water, the flame seems to expand. ***{I need to understand}*** *why the flame expands under the water.*

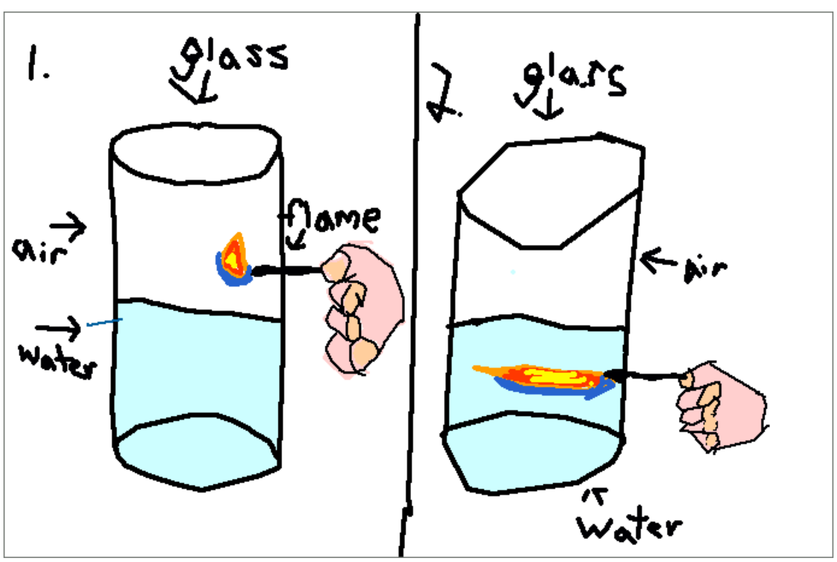

Figure 2: **Graphical representations of bending-light experiment in Grade 4.**

Source information

Although there were few graphical notes citing graphics or pictures from source material found on the Internet, in books, or from other authoritative sources, students did reference the text and pictures of their peers in Knowledge Forum. In Grade 3, of the total of 68 graphics produced, only 26.5% contained citations and they were all at the basic level. In Grade 4, 35 (29.1%) of the total of 120 graphics contained citations, with 28 (23.3%) rated at the basic level, 3 (2.5%) intermediate, and 4 (3.3%) at the advanced level.

Captions

Dyson (1982) and Edwards (1979) showed that drawing is positively correlated with writing as well as creative thinking and problem solving skills. In the current study, use of captions showed the greatest increase of all the seven dimensions from an average point score in Grade 3 of 0.95 to 2.25 in Grade 4. Text in graphical notes in Grade 4 was longer than in text-only notes, had more new and distinct words (words they had not used previously in their writing), and the relationship between text and graphic was clearer and more elaborate. Not only did Grade 4 draw more pictures, they produced more words, sentences, and idea units. This is illustrated in the note and drawing in Figure 3. The drawing and text maintain and support deep understanding, as Skupa (1985) indicates, as would be expected with use of appropriate captions. The note not only describes near-and-far sightedness, but touches on remedies in a series of four graphical representations with text and graphics closely aligned.

[**Title:** Concave and convex lenses] [**Problem:** What do they do?] by S.L., A.S.

{*New information*} *We read a reading about concave and convex lenses. A convex lens is shaped like belly and a concave is shaped like a cave. The thing we read about was far sighted and near sighted people and their glasses. A near sighted person (like S. L.) can see near objects clearly but they can't see far objects as clear[l]y. A far sighted person (like N. G.'s grandmother) can see far objects but can't see near objects that well. That's why those people need glasses.*

A near sighted person gets a concave lens because that lens helps them see. The reason people are nesr [near] sighted and far sighted all has to with the retina in your eye. To see clear[l]y the light has to focus exactly on the retina. You get near sighted when the light focuses before it gets to the retina. A concave lens makes the light go farther back so it gets to the retina. A far sighted person is far sighted because the light focusses [focuses] behind the retina. A convex lens makes the focus on the retina. Both of those lenses have to be perfect. That's why you need glasses (Note the text following this paragraph on the following screenshots.).

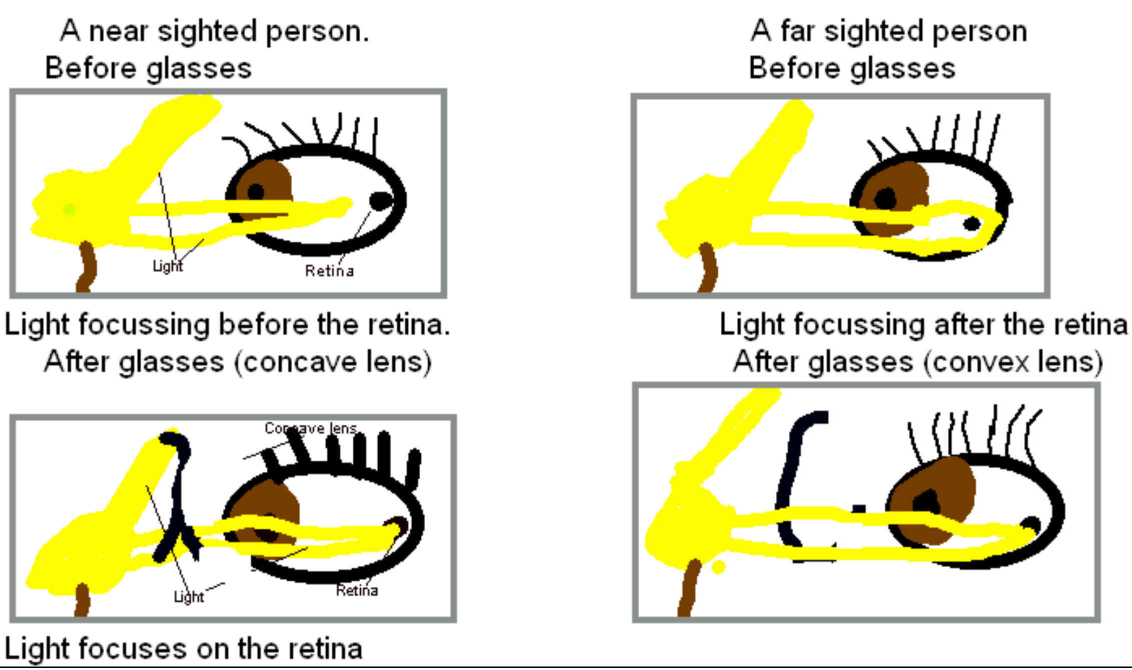

Figure 3: **Graphical representations of concave and convex lenses in Grade 4.**

Revisions

Revision of captions or drawings improves accuracy. The shift from an average point score of 1.73 in Grade 3 to 2.29 in Grade 4 reflects increases in use of precise vocabulary and efforts to correct inaccuracies. In Grade 3, there was an average of 4.43 revisions of 68 graphical representations for a total of 301 revisions and in Grade 4 an average of 6.68 revisions of 120 graphical representations for a total of 801 revisions. The increase in revisions from Grades 3 to 4 suggests students are working to present ideas more accurately and correctly.

Aesthetics

From Grade 3 to Grade 4, students showed an increase in use of devices to make drawings more visually appealing and colorful. The Grade 4 drawings were tidier, clearer, more detailed, conveyed more complex concepts, and had more captions and tags than those of the Grade 3 students (in terms of average point score, the shift was from 1.31 to 2.10). In Grade 3, of the total of 68 graphics 38 (55.9%) were judged to be aesthetically basic, 18 (26.5%) intermediate and 12 (17.6%) advanced. In Grade 4, for the total of 120 graphics the corresponding numbers were 25(20.8%), 46 (38.3%), and 49 (40.8%). As these numbers indicate, students at both grade levels produced aesthetically pleasing graphics, with substantial increases from Grade 3 to Grade 4.

Interpretive summaries/reflections

Although there were only a few graphical notes that summarized and provided high-level accounts of information, or reflected on the process of graphical representations for deep understanding, some examples could be found in Grade 4 (see for example Figure 4). In the course of their Knowledge Building, students raised questions and worked together, as authors contributing notes to their collective space for shared understanding and as co-authors improving ideas represented in their graphics. They also used “rise-aboves,” a note-type that allowed them to synthesize ideas from different notes into an integrated, higher-order framework. The question “why are rainbows so big on such small raindrops?” represents such an example (see the text inside the Figure 4).

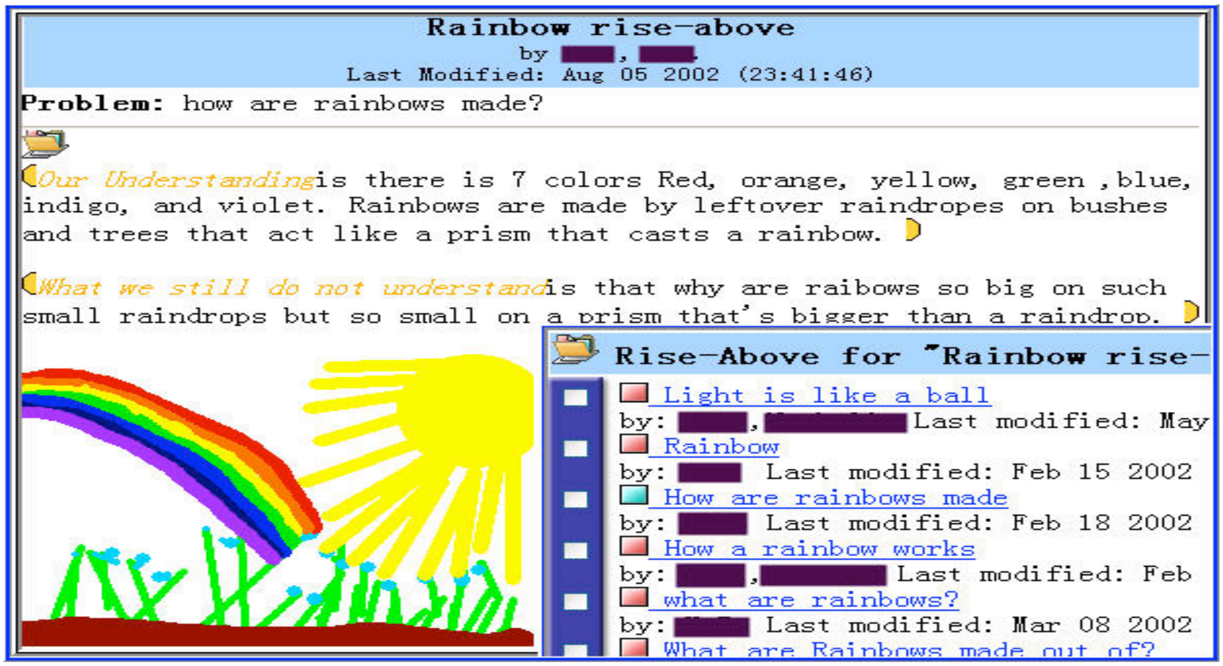

Figure 4: **A rise-above note on rainbows in the "Colors of Light" view in Grade 4.**

Figure 5 shows another type of interpretive summary and reflection. Students used the background of the view to organize their work, adding text and pictures to the background and arranging notes (square icon) and build-ons to notes (strings of notes with lines between them) to provide a high-level overview of their work. Students reflected: "What are our knowledge advances?" They recorded their "Knowledge Advances" with text or graphics, and as Figure 5 indicates, students drew five pictures representing their five theories for how light travels: "Wavy theory," "Straight lines," "Particle theory," "Combo theory," and "Ripple theory." The pictures were simple, visually appealing and easy to understand, and presented results of collective theory-building on how light travels.

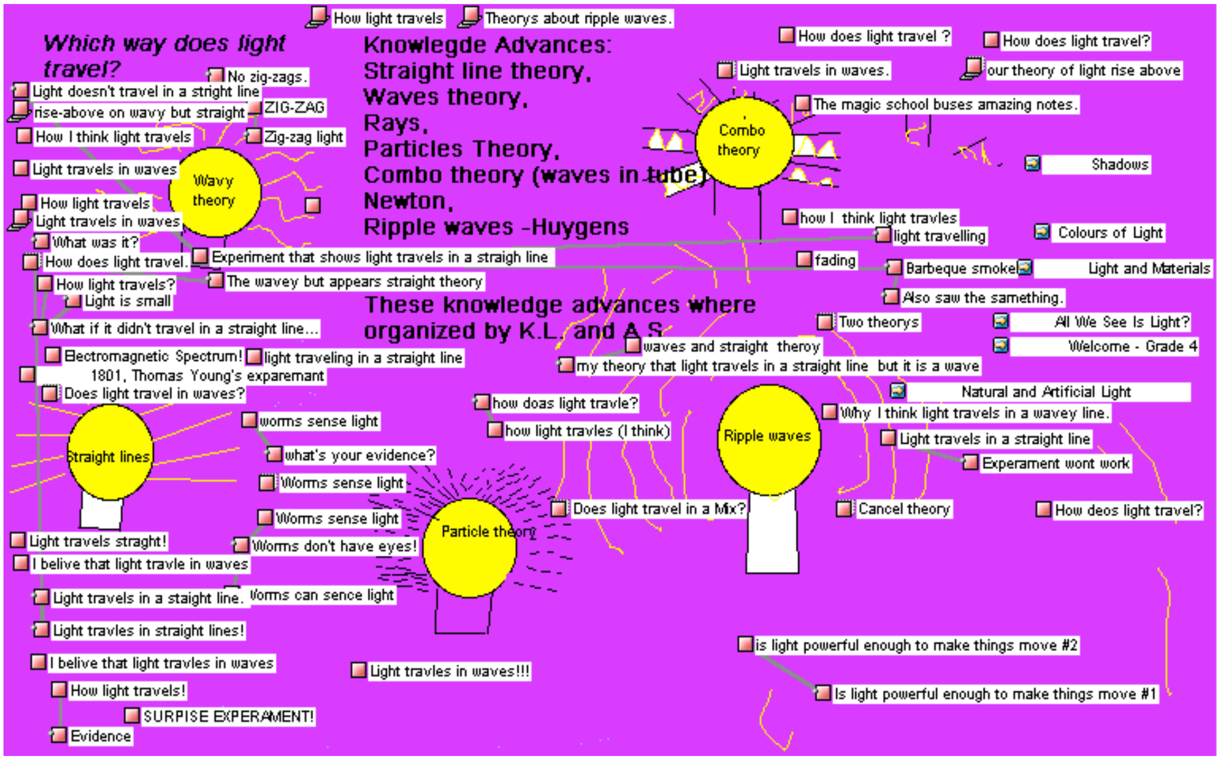

***Figure 5:* Graphical representation of knowledge advances as conveyed by Grade 4 students in a view they designed to convey how light travels.**

No graphic was judged to provide "Interpretive summaries/reflections" in Grade 3. In Grade 4, of the total of 120 drawings, 12 (10.0%) were judged to be at a basic level, 5 (4.2%), intermediate and 0 (0.0%) advanced.

Comparing Graphic Productions of Grade 4 and Grade 6 Students

The above results show change from Grade 3 to Grade 4. The question is whether the change represents the same rate of growth one might expect for any child advancing from Grade 3 to Grade 4 or whether the Knowledge Building pedagogy and technology helped students advance beyond normal expectations. To address this matter we assessed the quantity and quality of graphics for the Grade 4 students compared to Grade 6 students in the same school. Data for the Grade 6 class was collected in Knowledge Forum September 1998 to June 1999, before the school supported Knowledge Building across grade levels, so the Grade 6 students had no prior experience with Knowledge Building and Knowledge Forum. They did, however, have a rather special situation with a knowledgeable teacher-researcher who worked alongside the Grade 6 teacher to implement Knowledge Building pedagogy and technology. We reasoned that if normal maturation was the only factor, Grade 6 students would outperform the Grade 4 students consistently. But if Knowledge Building experience is an important factor, as we presume it is, then the Grade 4 students with a year more experience than the Grade 6 students would be reasonably close to the performance levels of the Grade 6 students.

The participants in Grade 6 included 22 students (10 girls, 12 boys). They used Knowledge Forum to record and collaboratively improve their ideas, just as students in Grades 3 and 4 did. The Grade 6 students studied flight (birds, airplanes, air pressure, buoyancy); biosphere (earth, weather, precipitation, forecasting); and outer space (stars, rockets, life and living in outer space). They produced a total of 68 graphics.

Content analysis and results of the Grade 4 and Grade 6 comparison

Students in Grade 4 (n=22) drew a total of 120 graphics, average 5.45 graphics per student, while students in Grade 6 (n=22) drew a total of 68 graphics for an average of 3.09 graphics per student; six students had no drawings. Interestingly, in sheer quantitative terms, the Grade 6 students with one year experience match the productivity of the Grade 3 students in this study. Grade 4 students wrote nearly the same number of words as Grade 6 students (average per graphic note in Grade 4 was 74.6 and for Grade 6 was 73.3). Additionally, Grade 4 students wrote more words per text note (49.7) than Grade 6 students (43.6), and produced more distinct words per note (30.0) than Grade 6 students (28.4). As indicated above, a distinct word is recorded every time a new word—one never appearing previously in the child's text—appears. Results suggest that students in Grade 4 are keeping pace with students in Grade 6 in entering new conceptual content into their notes. However they make more grammar and spelling mistakes.

Figure 6 and Table 2 show Grade 4 and Grade 6 comparisons based on content analyses of students' graphical representations rated on the 3-level, Basic-Intermediate-Advanced scale and quantitative results. In line with our expectation, based on the assumption that extended Knowledge Building experience would have important effects, Grade 4 students had, on average, higher scores than the Grade 6 students. Below we present the findings for the seven dimensions of graphical literacy that we assessed.

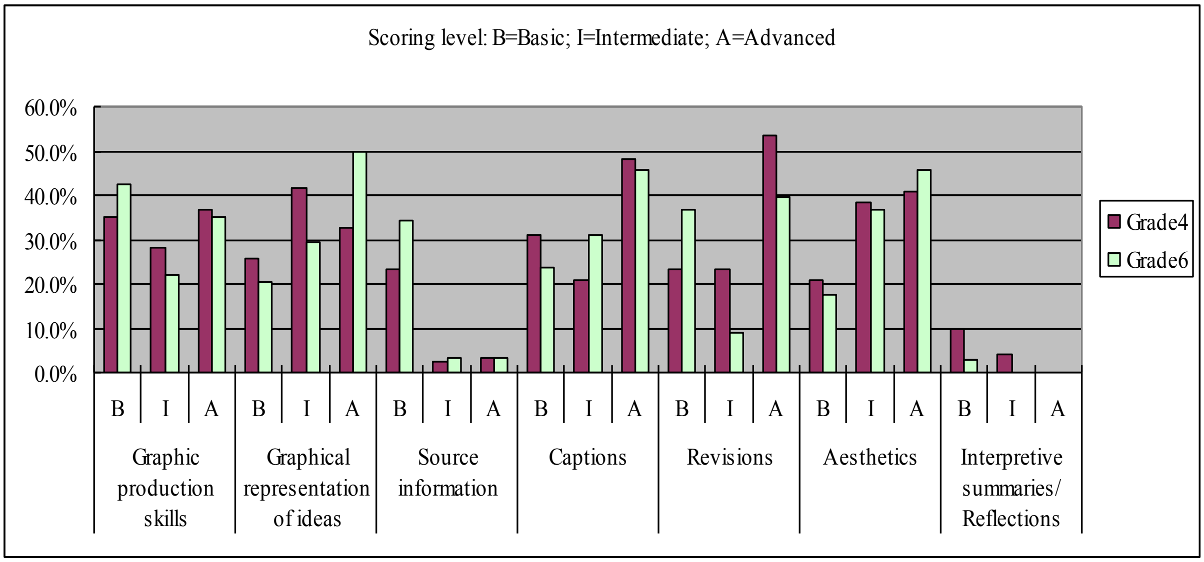

Figure 6: **Percentage of graphical notes demonstrating each of the seven different components of graphical literacy broken down according to Basic (B), Intermediate (I), or Advanced (A) levels of achievement: Grade 4 and Grade 6 Comparison.**

Table 2: *Number and Quality of Student-Generated Graphics: Grade 4 and Grade 6* Comparisons.

	Grade 4				Grade 6			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Number of Graphics	5.45	3.58	1	16	3.09	4.14	0	15
Quality of seven components of graphical literacy								
1. Graphic production skills	1.90	0.54	1	3	1.31	0.99	0	3
2. Graphical representation of ideas	2.01	0.46	1	2.91	1.55	1.09	0	3
3. Source information	0.42	0.26	0.1	1	0.77	1.7	0	3
4. Captions	2.25	0.5	1.5	3	1.49	1.02	0	3
5. Revisions	2.29	0.5	1.5	3	1.1	1	0	3
6. Aesthetics	2.1	0.54	1	3	1.55	1.14	0	3
7. Interpretive summaries/reflections	0.18	0.17	0	0.55	0.01	0.03	0	0.14

Note. Quality of student graphics was rated on a 3-point scale: (1) Basic = one point, (2) Intermediate = two points, and (3) Advanced = three points.

Graphic production skills. Grade 4 students demonstrated greater drawing skills than Grade 6 students, as indicated by the average basic-intermediate-advanced point score of 1.90 compared to the surprisingly lower score of 1.31 for the Grade 6 students. The Grade 4 students demonstrated more advanced skills through use of color, shape, dots, and so forth, leading to drawings judged to be more complex and advanced than those produced by Grade 6 students.

Graphical representation of ideas. For "Graphical representation of ideas," the average Grade 4 score of 2.01 was higher than the average Grade 6 score (1.55), but six out of the 22 students in Grade 6 did not produce a graphic. When we consider the graphics produced, and percentage of notes rated as more advanced, Grade 6 students outperformed Grade 4 students (see Figure 6) on graphical representations of ideas. They dealt with scientific concepts, theories, models, and working processes as represented in graphic form in more advanced ways.

Source information. Scores for both Grade 4 and Grade 6 students were low for "Source information," with Grade 4 students using fewer citations of source information (average point score of 0.42) compared to that of 0.77 for Grade 6 students. In Grade 6, students quoted other notes nine times, Internet websites four times, and cited 25 pictures from the Internet in 65 graphical notes. Grade 6 students seemed more aware than the Grade 4 of the importance of citing reference material.

Captions. Grade 4 students not only drew more pictures but they produced more captions, as reflected in their average point score of 2.25 compared to that of 1.49 for Grade 6 students.

Revision. Students in Grade 4 revised and elaborated their graphics more than Grade 6 students (average point score of 2.29 vs. 1.10). In Grade 4 the average number of revisions per note was 6.7 compared to 5.0 for Grade 6 students. It could be that Grade 6 students demonstrated more advanced abilities to start with and thus their entries required less revision.

Aesthetics. The average rating for aesthetic quality of graphics was also higher for Grade 4 students (average point score of 2.10 compared to 1.55 for Grade 6 students). The graphics in Grade 6 were tidier, clearer, and had more labels and tags, but were less colourful and more frequently produced with basic shapes from the drawing tools, while Grade 4 students tended to draw freehand, giving them greater scope for expression and aesthetic quality.

Interpretive summaries/reflections. Grade 4 students also outperformed Grade 6 students in the "Interpretive summaries/reflections" category. There were very few graphical notes in Grade 6 that summarized and provided high-level accounts of information, or reflected on the process of graphical representations for deep understanding. Although there were a few rise-above notes that synthesized ideas from different notes into integrated ones, there were no such notes using graphics with text.

Overall, even though the Grade 4 students were several years younger, they, on average, outperformed the Grade 6 students and seem to have gained significant graphical literacy skills beyond what would typically be expected at their grade level.

Conclusions and Implications

The purpose of this study was to produce an analytic scheme to assess growth in graphical literacy and to test the possibility that Knowledge Building pedagogy and technology would facilitate its growth. Graphics generated by 22 students over two years, Grades 3 to 4, were analyzed. These graphics were produced as students conducted their work in biology, history, and optics; the graphics that they produced while working in these different content areas were analyzed according to seven components of graphical literacy. We additionally compared the graphical literacy achievements of the Grade 4 students who had two years of experience, with those of Grade 6 students who had one year of Knowledge Building/Knowledge Forum experience. We did this to test our expectation that experience will lead to substantial gains beyond what can be expected on the basis of maturation alone. This proved to be the case.

Multiliteracies as by-products of Knowledge Building

Scardamalia (2003) proposed that Knowledge Building, with focus on conceptual advances in disciplinary understanding, conducted in a knowledge medium supporting multiple literacies, would result in increases in a broad range of literacies and 21st century competencies. A number of studies provide support for the idea that textual, dialogic, and scientific literacy are important by-products of Knowledge Building (e.g., Chuy et al., 2010; Moss & Beatty, 2010; Sun & Scardamalia, present issue; Zhang & Sun, in press; Zhang, Scardamalia, Lamon, Messina & Reeve, 2007). This study adds graphical literacy to the list. Well-controlled studies, using data and assessments in a variety of classroom settings, are required to replicate findings. What the current research contributes is an account of advances in textual and graphical literacy, including graphical thinking (manipulating drawing tools to represent a broad array of ideas), graphical learning (interacting with peers using graphical representations) and graphical communication (using diverse graphical representations for discourse, inquiry and idea improvement). These advances were made as students worked in core content areas, having received no direct instruction in graphical literacy and no explicit focus on it, thus supporting the idea of multiple literacies as a by-product of sustained Knowledge Building supported by Knowledge Forum's multimedia environment.

Expanding Knowledge Forum's capacity to enhance students' graphical literacy skills

Graves (1993) drew attention to the ways in which visual tools foster analysis, synthesis and meta-cognitive awareness; they also serve as "cognitive tools," scaffolding dialogue, reflection and learning (Jonassen & Reeves, 1997; Lajoie & Derry, 1993; McLoughlin, 1999; Rieber, 1995). Results suggest there may be advantages to enhancing the drawing and visualization tools in Knowledge Forum. For example, graphics scaffolds could be added to parallel text scaffolds, a palette of graphic symbols could be added, and so forth.

Coding scheme to measure growth in graphical literacy

Significant challenges face researchers and practitioners aiming to study, foster, and assess growth in graphical literacy: there are few studies to provide developmental accounts of graphical literacy; teachers find it is difficult to evaluate students' multimedia projects (Ohler, 2000), and different rules for assessing graphical literacy apply in different contexts (Hadjidemetriou & Williams, 2000, 2002; McMullen & Woo, 2000). In an effort to address these challenges a comprehensive coding scheme to assess graphical literacy was developed and applied to students in Grades 3, 4, and 6, with the scale comprehensive enough to assess advances in several different content areas. Future research will further refine and validate this coding scheme.

Overall, qualitative analysis showed significant increases in graphical literacy as students moved from Grades 3 to 4. These finding suggest that these literacies are mutually reinforcing and enhanced in the multimedia, communal environment known as Knowledge Forum. The extent to which they would appear in any multimedia rich educational context remains to be explored. Another finding of significance is that the graphics of Grade 4 students, on all seven dimensions of growth in graphical literacy, compared favorably with results from Grade 6 students who had less experience with Knowledge Building pedagogy and technology.

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