INTERPRETING AND EXPLAINING DATA REPRESENTATIONS: A COMPARISON ACROSS GRADES 1-7

Diana Arya

APPROACHES TO LIFESPAN WRITING RESEARCH

CHAPTER 11.

INTERPRETING AND EXPLAINING DATA REPRESENTATIONS: A COMPARISON ACROSS GRADES 1-7

Diana J. Arya
Anthony Clairmont
Sarah Hirsch
University of California, Santa Barbara

"Writing as a knowledge-making activity isn't limited to understanding writing as a single mode of communication but as a multimodal, performative activity" (Ball & Charlton, 2016, p. 43). One of these modes is graphical data representation. Situated in the visual, data representations are a critical part of visual culture. That is, "the relationship between what we see and what we know is always shifting and is a product of changing cultural contexts, public understanding, and modes of human communication" (Propen, 2012, p. xiv). What is little understood is how such knowledge develops across the lifespan. The developmental path to fluency in interpreting and analyzing various visual representations is largely unknown, yet such textual forms are increasing in presence across various disciplinary and social media outlets (Aparicio & Costa, 2015). Therefore, the development of competence in understanding and working with data representations is a critical part of the lifespan development of writing.

When we look at writing as a knowledge-making activity, the word and the image contribute to one another in an activity of meaning-making. As art historian John Berger attests in his seminal work, *Ways of Seeing,* (1972), writing and seeing aren't mutually exclusive, in that what we see "establishes our place in the surrounding world; [and we] explain that world with words" (p. 7). The interplay between the word and the image "asks students . . . to explore their assumption about images" (Propen, 2012, p. 199). These assumptions are central to our interests in learning how children develop meaning-making skills and critically engage with visual culture. How do young readers begin to develop ways to understand and access visual entities such as informational graphics and data charts or tables? Are there particular features that are more accessible than others? Are there patterns that we can detect and apply in curricular devel-

DOI: https://doi.org/10.37514/PER-B.2020.1053.2.11

opment with regards to data representations? Such questions guide the inquiry of this present study.

In his book, *Beautiful Data*, historian Orit Halpern (2015) describes how early representations of reality for the purpose of knowledge building moved from literal recreations of local individual entities (e.g., intricate renderings of flora and fauna as viewed by the naked eye) to increasingly complex phenomena that encompasses large assemblages of information across time. Halpern's historical account highlights the natural human inclination to make visible the unknown, and to understand the intricacies of reality. Readers of his account are taken on a historical journey that centers on renowned mathematician Norbert Wiener, popularizer of the term cybernetics. Wiener led the way to more expansive attempts to understand reality. His algorithmic contributions allowed for the process of aggregating copious amounts of information in order to represent past, present and future potentials for various phenomena of human interest. Born out of the demands of knowing as much as possible about the enemies of World War II, Wiener's work sparked a new aesthetic science of representing reality. The rise of visual representations of aggregated data (i.e., charts, tables and figures that reduces large amounts of information into consumable knowledge) in the decades following the war "saw a radical reconfiguration of vision, observation, and cognition that continues to inform our contemporary ideas of interactivity and interface" (Halpern, 2014, p. 249).

Minimally mentioned by Halpern (2014) is the work of statistician Edward Tufte (1983), who described the ideal (and less so) characteristics of visual displays of quantitative information. His seminal work is a critique of various historical and current examples of such graphical creations, highlighting the best and worst practices for articulating phenomena to intended audiences. He explains through these examples what counts as meaningful information as opposed to "chartjunk" (1983, p. 107), which includes irrelevant and potentially distorting elements (e.g., decorative features or seemingly engaging images) that waters down the "data density" of such graphical displays (p. 168). Tufte's recommendation to "maximize the data-ink ratio, within reason" (1982, p. 96 served as a guiding principle for our current study of how elementary students (grades 1-7) make sense of and compose interpretive messages about data representations that vary according to information density and presence of non-relevant content (1983). New school standards emphasizing the goals of understanding and applying graphical information for a variety of educational purposes (Lee et al., 2013; Next Generation Science Standards Lead States, 2013, Appendix M) offer a warrant for a deeper exploration into ways in which children across grades interpret and communicate such forms of textual information. To date, there are no such explorations to the best of our knowledge.

Within the grand historical context of visual representations of aggregated data (referred herein as data representations, or DRs), we can place a similar progression in the history of school science standards in the US. The earliest version of such standards is the Committee of Ten (National Education Association, 1894), from which we can view what aspects of visual representation were deemed most important for science education (among other disciplines). The expressed consensus among committee members was that "no text-book should be used . . . the study should constantly be associated with the study of literature, language and drawing" (1894, p. 27). Such declarations echo the early days of observing and recording natural phenomena like the 1728 work of famous knowledge gatherer and publisher Ephrain Chamber (1728), exampled in Figure 11.1. The representation of scientific knowledge was considered an essential task for students, but one which, like much Eurocentric education of the eighteenth and nineteenth centuries, emphasized copying rather than interpretation and communication.

Copying or tracing artifacts found in nature was a common convention of knowledge building for biologists. Thus, the practice of engaging in representative drawings from nature was a key standard for demonstrating university readiness (National Education Association, 1894).

Modern academic institutions no longer emphasize the development of such discrete representations of nature. Rather, today's school standards highlight the importance of textual reasoning and explaining aggregated information about various natural phenomena. This shift in standards has emerged in parallel with global, interdisciplinary concerns about the rising "prominence of data as social, political and cultural form" (Selwyn, 2015, p. 64) and the increasing need for helping students across the grade span to critically navigate such forms. Hence, developing practices of interpreting and analyzing DRs support the expressed need for all students to become "critical consumers of scientific information" (National Research Council, 2012, p. 41). While these needs are assuredly urgent, concerns about the ways that graphical displays of information are taken up and used by students and their teachers were documented well before the social media explosion made possible via the internet.

Gillespie (1993), for example, points out in her review of studies that very few students (approximately 4 percent) demonstrated mastery level understanding of graphic information presented in a standardized test (see also Kamm et al., 1977; National Assessment of Educational Progress, 1985). Gillespie (1993) highlights the importance for teachers to have explicit conversations with students about DRs that include sequential (e.g., flow charts) or quantitative (bar graphs or pie charts) information, maps, diagrams (blueprints or drawings), and tables or charts that allow for comparing and contrasting information. While she mentions the limitations of DRs embedded in basal textbooks, the source of this issue is the lack of variety in purpose and format rather than on information density as Tufte (1983) described (see also Hunter et al., 1987). Clearly, emerging scholarship on data representations will need to address Gillespie's concern with variety and utility as well as the matter of quality taken up by Tufte.

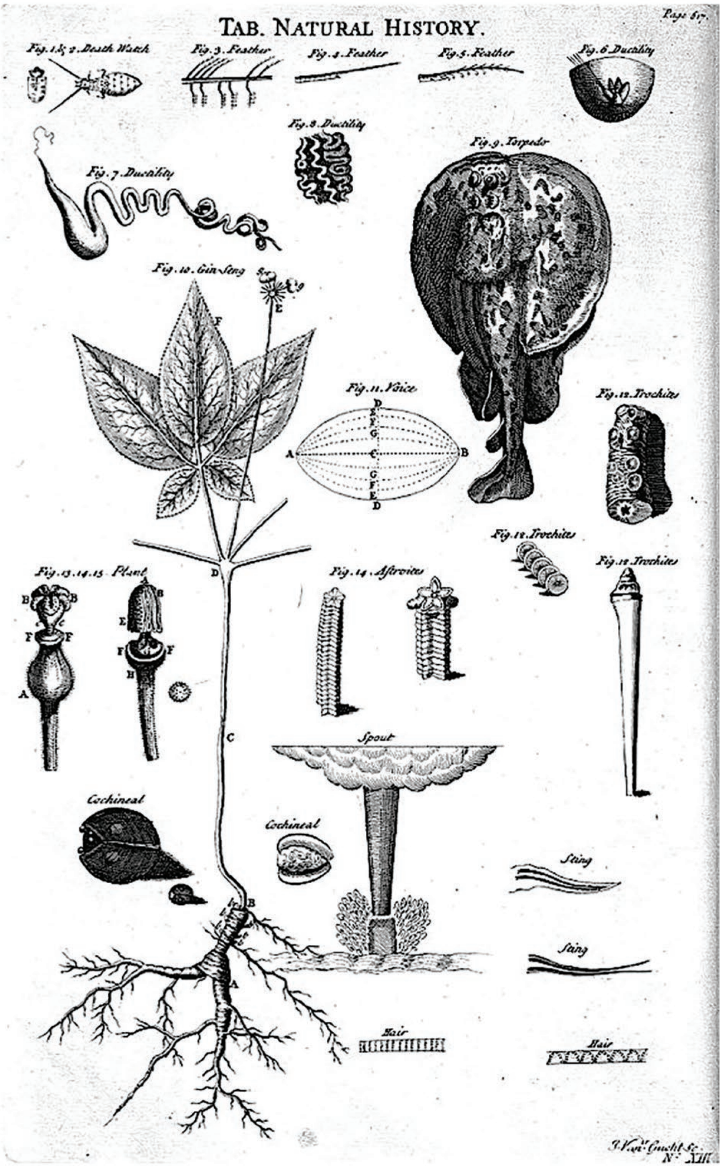


Figure 11.1. Drawings in Chamber's 1728 encyclopedia.

The need to foster student understanding of DRs has received greater attention in the most recent educational science standards, the Next Generation Science Standards (Next Generation Science Standards Lead States, 2013). The new standards provide rich descriptions about key scientific practices that students should begin learning in kindergarten, and that together comprise an idealized developmental sequence. One such practice is analyzing and interpreting data, which begins in the earliest grades (K–2) as making direct observations of phenomena to determine patterns (e.g., comparing the properties of various objects). Within this particular strand of practices, the notion of DRs is present in benchmark descriptions starting in the third grade; students in grades K-2 are expected to engage in analysis via exploration and experimentation of phenomena rather than graphical representations of such. Middle school students (grades 6–8), however, are expected to build on initial explorations of graphical displays to include pictorially captured data (e.g., photo images of microbial activity) and projections of activity across time. High school students are then expected to embark on the challenge of gathering and transforming information into visual representations and using them to support claims and explain phenomena. While no statement is provided to explain such a progression of standards or logic of development, readers can infer that (a) DRs are appropriate for children in grades 3–12, (b) DRs including future projections are more appropriate for students in grades 6–12, and (c) only high school students should be expected to create and transform data into DRs for making claims. However, these assumptions lack empirical support. Nor is there clarity about the variation of the purpose and complexity of DRs or guidance about whether certain forms with particular amounts of information should be introduced before others to form a developmentally appropriate sequence. There is also a lack of understanding about how teachers should introduce and support the exploration of DRs. Most concerning, there are no visual examples for teachers to understand the kinds of DRs that would be useful for particular grade bands. Research associated with "infographics" has thus far touted the importance and engaging nature of explicit discussions about DRs during classroom instruction (e.g., Kraus, 2012; Lamb et al., 2014; Martix & Hodson, 2014), yet like the new scientific standards, such research lacks a developmental view of such instruction across the K–12 spectrum.

This study traces our initial exploration of how 28 students across grades 1–7, who represent various sociocultural backgrounds, understand and compose interpretations of DRs in small-group, collaborative discussions. Using a communities of practice lens (Gee, 2005), we systematically explored video-recorded, focus group discussions about various selected data representations and all written explanations produced during these sessions. We view this initial exploration as a beginning point for building a testable theory about the developmental trajectory for interpreting and analyzing DRs. By including participants from different grade levels, we have the opportunity to compare and contrast how groups of students representing different stages of development respond to DRs, and such an approach has long been noted to be effective for revealing key aspects of knowledge and skill development (Bruner, 1990). Hence, we addressed the following lines of inquiry: What are the general patterns observed in recorded discussions and composed explanations about DRs among different grade-level groups? What do these patterns reveal about the development of and instructional support for fostering skills and abilities needed for sense making and communicating about DRs? Such questions support our overarching goal of this study, which explores how elementary students across grades 1 through 7 interpret and explain the phenomena DRs aim to communicate.

METHODOLOGY

Participants

A total of 28 children (nine identified as female and 19 male) ranging in ages 6 to 13 participated in one of 10 focus groups, each organized by grade level. Based on reported information from parents, participants represented a range of cultural backgrounds that included 14 (50%) White, 11 (39%) Latinx, and three (11%) Asian students. The majority of students (18 in total, 64%) reported English as their home language while seven (21%) reported Spanish as the main language used at home. Two participants (7%) reported Tagalog as their home language. The remaining student spoke Mandarin as the home language. Participants also represented a range of schooling experiences and associated activities. All participants attend public or private elementary and junior high schools within the same local community. Based on reported information from parents, 10 students received special education services during the regular school year.

Selection of DRs

A total of 11 DRs were selected for this study. A panel of five researchers (two graduate students, two junior faculty members and one senior faculty member) engaged in three planning sessions that involved gathering and reviewing potential DR candidates. Final selection was determined by topic relevance (e.g., ethnicities of movie characters) and by representing a wide range of aspects identified by Tufte (1983), including informational density and the presence of non-relevant information. Figure 11.2 represents the varied complexity of the selected DRs.

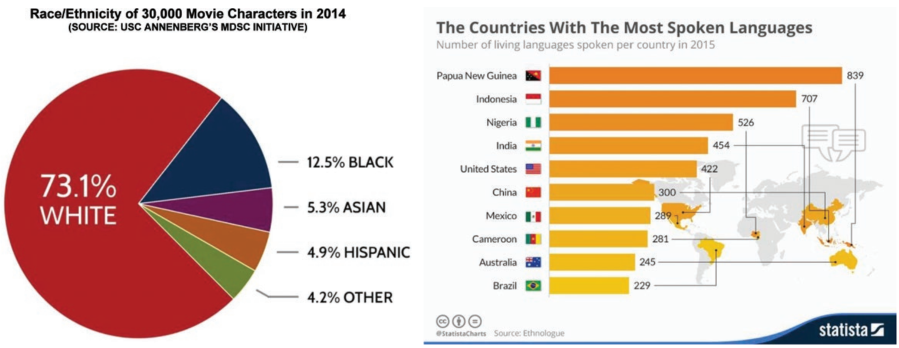


Figure 11.2. Images of two selected DRs.

A previous pilot study involving 25 fourth grade participants informed the final selection of and discussion guide for the DRs included in the present study.

Context and Data Sources

All participants attended a summer literacy camp during the time of this study (2018). The camp took place at a local research university that houses a center designed to provide intensive literacy support for students in grades K–8. The children's center supports students with a wide range of backgrounds and abilities during the school year; children enter the program either through family referral or through partnership programs with neighboring schools and after-school clubs. Summer camp takes place during the month of July and is available on a first come, first served basis. All summer camp attendees were organized by grade level and further divided into groups with no more than 6 members.

The present study took place over a two-day period during summer camp. All instructors received two training sessions on the use of the discussion protocol (a revised version from the previous pilot) and facilitating responses while avoiding additional prompting and scaffolding beyond the protocol prompts (e.g., please say more about that; what do others think?). Based on instructors' observations of interpersonal dynamics and personalities, some of the groups were further divided to ensure that all members would have the opportunity to contribute to group discussions about a small set (three in total) of DRs. Each group engaged in three distinct discussion events marked by the introduction of a DR and either wrote explanations of each individually or collectively via dictation. Table 11.1 presents information about recorded discussion events for each group.

Table 11.1. Overview of DR Discussion Groups

Group	Grade Level	Number of Students	Duration of Recorded Discussions	Number of Written Explanations Produced**
Group A	1	3	29:25	3
Group B	2	2	24:06	4
Group C	2	1*	22:35	1
Group D	2	2	35:09	3
Group E	3	2	39:49	3
Group F	4	2	1:01:48	3
Group G	4	3	39:12	5
Group H	5	5	1:49:58	6
Group I	6	5	50:11	6
Group J	7	3	14:20	2

** Based on particular instructional needs of this student who has autism, exchanges excluded other students.*

***For all groups in grades 1–3, written explanations were expected to be collected via dictation.*

Discussion Process

Instructors presented each of three different data representations (i.e., representations that varied in density of graphical elements and conceptual meaning) in separate succession, asking the group to respond to questions including the following: What do you see? What do you think the person who made this wanted to say? What does this make you wonder? Facilitating instructors followed up with clarifying questions (e.g., tell me more) and questions designed to elicit a critical assessment (What do you want to know more about? What advice do you have for the author?). Following discussion, all groups collectively composed interpretations of the first two DRs and selected one of these to collaboratively compose an explanation for a student in a younger grade. Groups in higher grades (fourth graders and older) were expected to compose their own individual interpretations of the third and final DR presented, while younger groups continued to collectively compose interpretations that instructors captured verbatim. However, participants in the sixth and seventh grade groups (Groups I & J) did not complete their written explanation of this third DR due to time constraints related with the summer program. Further, the seventh-grade participants expressed their interest in using the available whiteboard to compose explanations of the first two DRs and as such, one student served as scribe for the group.

All discussions were video recorded using an iPad. Instructors invited student participants to decide where the iPad should be placed within the room in order to capture their discussion. The sessions began with an explanation that scientists want to learn from children how to make their work easier to understand. As such, participants were positioned from the beginning as "cultural guides" (Green et al., 2007) to help the instructor learn what was meaningful, useful, confusing, or lacking about each of the presented DRs from the students' perspectives.

Families of participating children were first informed of the study and prior to the recorded sessions via the camp newsletter, which included the explanation of our goal to help students across the grades develop critical reasoning skills required for understanding and explaining the ever increasing number of tables and graphics in various school-related texts. English and Spanish versions of the newsletter were available to families. All participating children had signed consent from their parents to participate in the study.

Analytic Framework

Units of analysis were organized by discussion event (Bloome et al., 2004), which was bounded according to each DR presented to the group. All video recorded sessions were reviewed separately by two researchers who identified levels of collaboration and communicative moves during group discussions. Following Gee's (2005) Communities of Practice (COP) framework, analysis centered on the social space rather than on individuals. As such, we focused on instances of "mutual engagement" according to constructs of interest among members of the group (p. 592). We analyzed efforts in sense making and explaining through the constructs of "collaboration" and "communicative moves" as informed by prior research. Specifically, our construct map for gauging levels of collaboration during reading discussions was informed by theoretical frames from psychology (Vygotsky, 1980), sociology (Hutchins, 1991), discourse analysis (Gee, 2004), and the learning sciences (Hershowitz et al., 2001; Johnson & Johnson, 1990). Figure 11.3 features the construct map we developed with the guidance of the BEAR Assessment framework (Wilson, 2004) for analysis of video recorded discussions. Thus, this framework takes a "building block" approach for educational assessment practices; construct maps serve as the first step in gauging development.

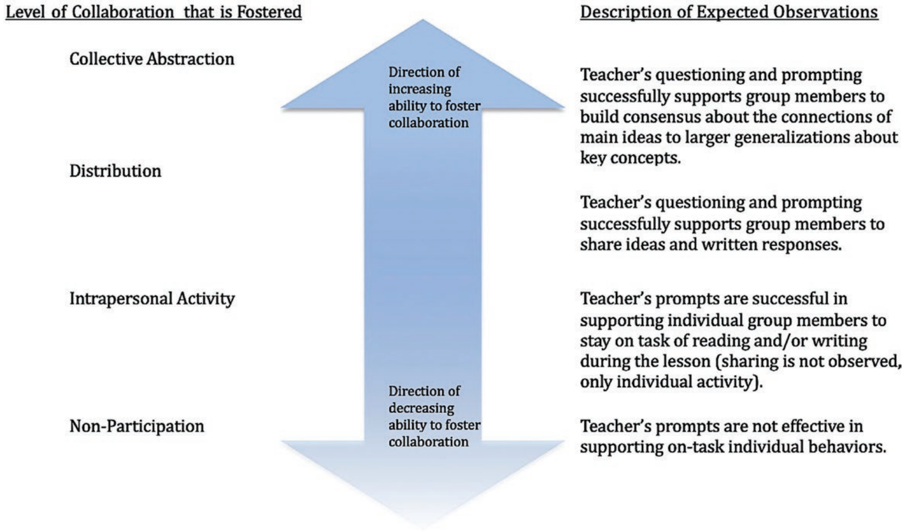


Figure 11.3. Construct map for levels of collaboration.

We further investigated the particular communicative moves demonstrated during instances of collaboration (distribution, building, and collective abstraction). Based on our research of potential communicative moves for comprehending and explaining phenomena and previous findings from our pilot study, we selected the following four codes for our analysis: narrative, or narrativizing (Bruner, 1990), focusing illusion (Kahneman et al., 2006) or the attention to familiar yet not necessarily salient ideas (Gillespie, 1993; Groes, 2016), connecting with prior knowledge and experiences and use of multimodal resources (Cole, 1998). Any inconsistencies between analyses of a common discussion were deliberated as a team and resolved with little difficulty. While there were a few disagreements in perceived levels of collaboration, there were no inconsistencies with identified communicative codes. Transcriptions of video-recorded interactions followed micro-ethnographic devices by Bloome et al. (2004) that focus on how the assertions were uttered, which follow the general structure of message units. Phatic displays were captured in bold text and indications of questioning were marked with an upwardly directed arrow ("↑") in order to further contextualize transcribed commentary.

FINDINGS

General Lack of Exposure and Practice

Preliminary findings from analysis of video-recorded discussions suggest that students in earlier grades (i.e., third grade and younger) have varied levels of exposure to data representations in school as part of a lesson or activity. For example, a third-grade student from one school had no experience with such representations (I've never seen anything like this) while another third grader from a different school had moderate exposure (this line means growth). Those familiar with the basic formats presented (e.g., pie charts) generally reported learning about them outside of school via popular media or news. Basic interpretational tasks were highly laborious or out of reach for most of the students in our study. This finding was consistent in our previous pilot study, which also included data representations along a wide continuum of difficulty and a variety of topics.

Student Collaboration

Our theory of development involved three collaborative levels: Distribution (students sharing without connecting to each other's comments); Building (students adding to or evaluating comments from others); and Collective Abstraction (students collectively working together towards larger generalizations). Of these three levels, the most common was Distribution. Among the young students especially, there was a lot of sharing and working through ideas but rarely were students responding to each other's comments. While we observed instances of thinking aloud, this form of thinking was rarely realized collectively. The next level observed was Building, as some groups did show instances in which students were working off one another's comments in their attempt to identify the DR message(s). The instances of Building were mostly attributed to the older students in grades 4–7. There were very few demonstrations of Collective Abstraction; such instances involved two students who took the lead in explaining the DR to others who were either confused or disengaged.

Requesting Textual Explanations for DRs

When soliciting feedback from students about what might be improved about each graphic, more textual description was the most common substantive request. Paradoxically, during the actual process of interpreting data representations, students delayed reading the text that was available. This neglected text, such as titles and legends, included information essential to the intended messages of the data representation. In some cases, students worked to interpret data representations for periods exceeding ten minutes without mentioning, or apparently noticing, key text. This pattern was more prevalent among younger students, particularly those in grades 1–4. Sixth graders, however, read the titles first and moved quickly to accurate interpretations of the graphics.

The Focusing Illusion

Creating narratives about the content of data representations is a task that seemed somewhat easier for children in older grades. A successful account of the messages communicated by data representations necessarily involved narration, but not all potential narratives were plausible. We found that students sought to narrativize aspects of the DRs even before registering the presence and meaning of all available information. For example, second- and third-grade students became so focused on the fact that the DR contained a map of the US that they did not mention any other element of the graphic in their subsequent narratives, all of which centered on geography or the map's color scheme. Borrowing a term from heuristics research in behavioral economics, we call this phenomenon a focusing illusion (Kahneman et al., 2006). The illusion occurs when people implicitly give too much importance to small features of a larger whole, effectively ignoring or downplaying information outside the temporary locus of attention (Kahneman, 2011).

From Interpretation to Writing

The findings described above were informative of the written products from students. Expectedly, patterns identified in written expressions produced during DR discussions echo the communicative moves identified during verbal interactions. For example, Figure 11.4 shows a stylized pie chart that was presented to groups representing grades 1–5. This DR elicited a focusing illusion (apples) from the first and second graders while the interpretation of the third-grade students captured the key point (spending habits of children). The following exchange between a first-grade student ("S") and the instructor ("I") demonstrates this focusing illusion:

I: what do you think that this picture means↑

S: food

I: food

why do you think it means food↑

S: because it's an apple

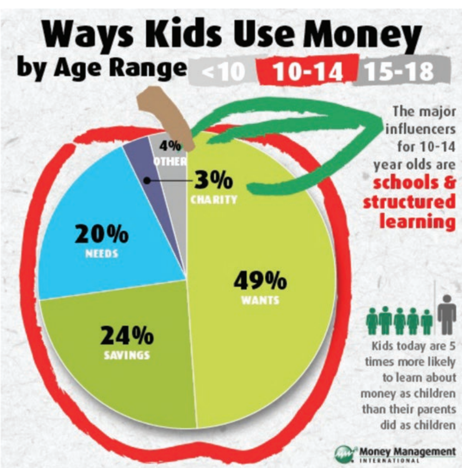
and an apple is a food

The first-grade student goes on to explain that the apple is "organic" and that is grown from a tree, and that more apples can be grown using apple seeds. However, the shape of the pie chart is a superficial element of the data representation. The students' focus on this detail (what we identified as a focusing illusion) spawns a narrative that derails the interpretative process. Likewise tripped by chartjunk, the second graders have a similar conversation, fixing their attention on both the apple shape and the colors. The third-grade students, by contrast, are able to discern that the shape of the pie chart is a superficial element ("It's shaped like an apple. They try to make it interesting for kids."). While the apple shape is the also the first element noted by the third-grade students, they quickly move away from this observation, as shown in the following exchange:

I: Tell me what you see
and how would you explain it
to someone who is younger
S: Uhhh
pie chart↑
I: say there's a younger student
what's the first thing you would tell them↑
S: this is how kids use money↑

The students' prior familiarity with at least one format of data representation—the pie chart—as well as his early attention paid to the title, grounds a plausible interpretation of the data representation.

The two examples featured above were typical of the patterns of discourse that preceded writing about DRs across grade groups. Figure 11.4 includes the most representative explanations produced either through dictation or individual writing by each of the grade-level groups; original spelling and grammatical structure for handwritten accounts from students in grades four and five were maintained.



(Grade 1) *It's an apple. Partly purple apple means it has lots of juice. They grow from trees. I notice it has one leaf. There are five people. There's a stem.*

(Grade 2) *There's green, white, blue, purple, and grey. There's an apple shape.*

(Grade 3) *This is how kids use money. This is how kids use math. It's an apple. It's shaped like an apple. They try to make it interesting for kids. Charity needs money. Only three percent. That's small. It's a pie chart. These kids use money. That's what it says.*

(Grade 4) *It is basically an apple that has pie chart about you use money wisely. The brand Money Management. Don't buy anything that is useless.*

(Grade 5) *The chart shows how kids use their money. 3% of the kids use their money for charity, and 49% of kids use their money to get stuff they want. Some kids save their money for their collage funds, and 20% of the kids use their money for the need like to buy cloths and stuff.*

Figure 11.4. Third DR presented to groups with associated written explanations.

The progression of communicative moves observed across such composed explanations highlight a general movement in constructing narratives anchored by a focusing illusion (grade 1) towards narratives focused on key textual ideas (grade 5). The various observed communicative moves from participants, such as narrativizing and making connections utilizing prior knowledge, were not prompted by the instructors, nor was there any indication that students were drawing on any specific techniques previously taught in school.

DISCUSSION

Findings from our present study suggest that the developmental lifespan for understanding and explaining data representations (or infographics) begins in early grades with an over-emphasized eye on familiar objects or concepts (e.g., an apple), from which less textually relevant narratives are constructed. Students in older grades tend to use more (but sparingly) textual information to anchor understandings about the DR. While there seems to be a developmental shift across grades (as represented in Figure 11.4), we observed a general struggle in understanding key information presented in charts, graphs, maps, tables, diagrams and drawings. Further, there is evidence of variability in exposure to DRs for children within the same grade. Such observed variability within a local community context suggests that young students may not have consistent opportunities to explore data representations. This finding runs contrary to current educational standards, which emphasize the importance of teaching such scientific practices beginning in kindergarten, hence making resources and activities "accessible to younger students but . . . broad enough to sustain continued investigation over years" (NRC, 2012, p. 31). Findings from analysis of group discussion suggests that the following practices develop across the represented grades:

- Collaborative thinking and knowledge building (moving from disconnected sharing toward abstraction),
- Narrative explanations (moving from focusing illusions toward graphically anchored connections), and
- Critical synthesis of presented elements (moving from discrete explanations toward critical analysis).
- Such observed differences between student groups organized by grade level suggests that across the lifespan, one's communicative understanding of DRs grows along with collaborative skills and multiple exposure to various textual sources.

We found that graphical information generally constitutes a mode of communication that many students find difficult to interpret. This finding highlights the need for explicit instruction for supporting development of such critical reading skills. This need is particularly important in light of the general increase in the number of DRs that children are encountering both in their textbooks and in the media that surrounds them (Lamb et al., 2014). As noted, participants who recognized aspects of the DRs mentioned that they had seen something like the graphic in math class, on the news, or even in a movie. Therefore, we can conclude that students are encountering DRs regularly among a variety of different formats and environments, even if they don't identify them as such. However, mere recognition is insufficient given the inherent complexities of DRs, coupled with the pedagogical exigencies of current educational standards.

As mentioned in the findings, many of the students desired more textual information to help with explanation of graphical displays, yet most groups (particularly those of younger grades) seem to avoid using the text already available to them in titles and embedded text. In future research, we hope to better understand this disjuncture between stated desires and performance. By modeling different techniques with which to approach data representations in the classroom, much like how a math formula is explained or complete sentence composition is demonstrated, teachers could demonstrate potential approaches for students while attempting to interpret DRs. Such instruction may help students gain greater understanding about aggregate data by regularly incorporating such modalities into classroom practices. Further, students in early grades may become more comfortable with engaging in such a modality, hence curtailing focusing illusions and non-relevant narrativization.

We suspect that the low levels of engagement and collaboration shown by some students is a side effect of confusion. DRs represent a wide range of relevance and accessibility and as such, students would benefit from activities that would enable ample practice in engaging with such complex academic texts. If the student has had little to no prior exposure to a particular type of graphic (e.g., regression line across time), but has received explicit instruction about the general nature and purpose of DRs, the tasks of understanding and articulating may become more engaging and even enjoyable, hence positioning the activity as an opportunity to discover something new about the world. The ubiquitous nature of DRs has elevated this need to support such readerly opportunities for discovery.

The recorded group discussions described in this study provided a way of seeing how students develop sense making and interpreting DRs across the gradespan. From this initial phase of exploration, we have the foundations for a theory of development that may inform how teachers can support students' communicative proficiency with DRs. For example, findings presented here may inform the selection of particular graphics for particular grade bands for class activities (e.g., pie charts and bar graphs with minimal seductive elements for earlier grades). We have found that such grade-appropriate variation will indeed involve a closer examination of informational density and conceptual relevance. With collaborative levels and communicative moves identified, next empirical stages will include iterative, large-scale investigations. Specifically, we aim to create systematically varied DRs to test emerging theories about the effects of informational density and conceptual relevance on sense making and explanation from students across grades 1–7.

REFERENCES

Aparicio, M., & Costa, C. J. (2015). Data visualization. *Communication Design Quarterly Review*, *3*(1), 7-11.

Ball, C. E., & Charlton, C. (2016). All writing is multimodal. In L. Adler-Kassner & E. Wardle (Eds.), *Naming what we know: Threshold concepts of writing studies*. (classroom ed., pp. 42-43). Utah State University Press.

Berger, J. (1972). *Ways of seeing*. BBC and Penguin.

Bloome, D., Carter, S. P., Christian, B. M., Otto, S., & Shuart-Faris, N. (2004). *Discourse analysis and the study of classroom language and literacy events: A microethnographic perspective*. Routledge.

Bruner, J. (1990). Culture and human development: A new look. *Human Development*, *33*(6), 344-355.

Cole, M. (1998). Can cultural psychology help us think about diversity?. *Mind, Culture, and Activity*, *5*(4), 291-304.

Gee, J. P. (2004). *An introduction to discourse analysis: Theory and method*. Routledge.

Gee, J. P. (2005). Meaning making, communities of practice, and analytical toolkits. *Journal of Sociolinguistics*, *9*(4), 590-594.

Gillespie, C. S. (1993). Reading graphic displays: What teachers should know. *Journal of Reading*, *36*(5), 350-354.

Green, J., Skukauskaite, A., Dixon, C., & Córdova, R. (2007). Epistemological issues in the analysis of video records: Interactional ethnography as a logic of inquiry. In R. Goldman, R. Pea, B. Barron, & S. J. Derry (Eds.), *Video Research in the Learning Sciences* (pp. 115-132). Lawrence Erlbaum.

Groes, S. (2016). Against nostalgia: Climate change art and memory. In S. Groes (Ed.), *Memory in the twenty-first century* (pp. 175-187). Palgrave Macmillan.

Halpern, O. (2015). *Beautiful data: A history of vision and reason since 1945*. Duke University Press.

Hershkowitz, R., Schwarz, B. B., & Dreyfus, T. (2001). Abstraction in context: Epistemic actions. *Journal for Research in Mathematics Education*, 195-222.

Hunter, B., Crismore, A., & Pearson, P. (1987). Visual displays in basal readers and social studies textbooks. In D. Willows & H. Houghton (Eds.), *The psychology of illustration* (Vol. 1, pp. 116-135). Springer-Verlag.

Johnson, D. W., & Johnson, R. T. (1990). *Cooperative learning and achievement.* In S. Sharan (Ed.), *Cooperative learning: Theory and research* (p. 23–37). Praeger Publishers.

Kahneman, D. (2011). *Thinking, fast and slow*. Farrar, Straus and Giroux.

Kahneman, D., Krueger, A. B., Schkade, D., Schwarz, N., & Stone, A. A. (2006). Would you be happier if you were richer? A focusing illusion. *Science*, *312*(5782), 1908-1910.

Kamm, K., Askov, E., & Klumb, R. (1977). Study skills mastery among middle and high school students. ERIC Document Reproduction Service No. ED 141 780.

Lamb, G. R., Polman, J. L., Newman, A., & Smith, C. G. (2014). Science news infographics: Teaching students to gather, interpret, and present information graphically. *The Science Teacher*, *81*(3), 25.

Lee, O., Quinn, H., & Valdés, G. (2013). Science and language for English language learners in relation to Next Generation Science Standards and with implications for Common Core State Standards for English language arts and mathematics. *Educational Researcher*, *42*(4), 223-233.

Martix, S., & Hodson, J. (2014). Teaching with infographics: Practising new digital competencies and visual literacies. *Journal of Pedagogic Development*, *3*(2), 17-27.

National Assessment of Educational Progress (NAEP). (1985). National assessment of education progress, reading in America: A perspective on two assessments (Report 06-R-01). United States GPO.

National Education Association. (1894). *The report of the committee of ten*. American Book Company.

National Research Council. (2012). *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas*. The National Academies Press.

Next Generation Science Standards (NGSS) Lead States. (2013). *Next generation science standards: For states, by states*. The National Academies Press.

Propen, A. D. (2012). *Locating visual-material rhetorics: The map, the mill, & the GPS*. Parlor Press.

Selwyn, N. (2015). Data entry: towards the critical study of digital data and education. *Learning, Media and Technology*, *40*(1), 64-82.

Tufte, E. R. (1983). *The visual display of quantitative information*. Graphics Press.

Vygotsky, L. S. (1980). *Mind in society: The development of higher psychological processes*. Harvard University Press.

Wilson, M. (2004). *Constructing measures: An item response modeling approach*. Routledge.