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Developing young adults' representational competence through infographic-based science news reporting

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ABSTRACT
This study presents descriptive analysis of young adults' use of multiple representations in the context of science news reporting. Across one semester, 71 high school students, in a socioeconomically diverse suburban secondary school in Midwestern United States, participated in activities of researching science topics of their choice and producing infographic-based science news for possible online publication. An external editor reviewed their draft infographics and provided comments for subsequent revision. Students also provided peer feedback to the draft version of infographics using an online commentary tool. We analysed the nature of representations students used as well as the comments from peer and the editor feedback. Results showed both students' capabilities and challenges in learning with representations in this context. Students frequently rely on using certain kinds of representations that are depictive in nature, and supporting their progress towards using more abstract representations requires special attention and identifying learning gaps. Results also showed that students were able to determine representational adequacy in the context of providing peer feedback. The study has implication for research and instruction using infographics as expressive tools to support learning.

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Representational competence; infographics; visual representations; science literacy; multiple representations

Introduction

Infographics are increasingly used as a means of organising, visualising, and communicating data and ideas related to science, technology, engineering, and mathematics (STEM). Media outlets ranging from *Visual.ly* and *good.is* to *The New York Times*, *The Guardian*, and *Wired* regularly use infographics to communicate science to the public. Organisations use infographics to communicate information in visually appealing and, hopefully, readily understandable form. For example, the US Centers for Disease Control and Prevention (CDC) has an 'Infographic' section on its website that presents data on global health (http://www.cdc.gov/globalhealth/infographics/default.html). The increasing prevalence of this genre in public communication of STEM creates a need for developing a particular aspect of young adults' scientific literacy – the ability to understand and make use of

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published infographics, determine the credibility of the reported content, and contribute to ongoing science-related conversations.

Questions about young adults' abilities relate to both the content and inscriptional (tools) aspects of science literacy (Gilbert, 2008; Latour, 1986; Lemke, 1998a). Based on a 20-year survey of undergraduates' knowledge of science literacy in the United States, Impey, Buxner, Antonellis, Johnson, and King (2011) reported that 'beliefs in pseudoscience run high' among university students and their scientific literacy is marginally better than that of the general public (p. 31). Studies also suggest that young adults struggle to understand and make use of visual representations (e.g. Bowen & Roth, 2002). It will be useful to understand and develop young adults' abilities to make sense of the multifaceted STEM-related data displays and arguments in infographics because critiquing and creating infographic-based science news holds some promise as a means to develop critical STEM literacy (Polman & Gebre, 2015).

Infographics are a genre that uses visual representations of data and ideas to communicate to audiences that are usually within the general public rather than to scientific communities (Polman & Gebre, 2015). Infographics are sometimes referred to as data visualisations. However, they are not just graphs or charts created from quantitative data as they often include qualitative representations and cues to illustrate and differentiate ideas. Infographics also combine different kinds of visualisations and representations. In essence, infographics are ways of organising and presenting arguments and stories about a phenomenon. As such, they represent the producer's understanding of the represented phenomenon. Constructing a meaningful infographic can be considered to be similar to writing a passage about a given topic, albeit in a visual form that has affordances and constraints differing from written texts. For instance, not only are the multiple forms of representation that make up an infographic important; the layout and system of relations of the representations within an infographic often conveys meaning. Infographics use different representational tools (e.g. shapes, colours, and alignment) and they often have visual appeal to the readers. However, they are often created by graphic designers and journalists for lay audience, rather than by scientists for the scientific community. It is possible that both sides of a given issue may not be represented or data selection and organisation may not be neutral, there by necessitating skills on the part of the reader to determine the credibility and neutrality of reporting.

From the perspective of learning and instruction, infographics are learning tools that facilitate construction of knowledge and mediate students' learning (Palincsar, 1998; Wertsch, 1998). Scholars use different terms to refer to the simultaneous use of different forms of representation in science such as 'visualisation' (Gilbert, 2008), 'multiple representations' (e.g. Ainsworth, 2006, 2008; Yore & Hand, 2010), 'representational competence' (Stieff, 2011) and 'meta-representational competence' (diSessa & Sherin, 2000), to mention some. We use the phrase 'multiple representations' to refer to the various visual tools and their use in students' learning, whereas we use 'representational competence' to focus more on the capabilities of learners to construct and use multiple representations.

In our study, it is important we consider both the process aspect of students creating representations and the nature of the representations generated by students. Similar to diSessa and Sherin (2000), we focus on any capabilities students have related to representations as opposed to focusing only on learned representations such as graphs and formulas. diSessa and Sherin (2000) used 'meta-representational competence' (MRC) and defined it as

> the full range of capabilities that students (and others) have concerning the construction and use of external representations. … [It] includes the ability to select, produce and productively use representations but also the abilities to critique and modify representations and even to design completely new representations. (p. 387)

We found the concept of meta-representational competence useful in our work, as it involves the use of representations as generative learning tools where students actively engage in constructing, representing and communicating knowledge. However, based on our interactions with other scholars in the field (including in the review of this manuscript), the use of the prefix 'meta' appears to be confusing as to whether it relates to a higher level of representational competence, similar to 'meta-cognition'. Accordingly, in this paper we use 'representational competence' to refer to students' abilities to create, understand, use, and critique multiple representations.

This paper is based on a broader project on developing young adults' STEM literacy through collaborative work of critiquing and creating infographics. Focusing on the representation aspect of STEM literacy, this descriptive study investigates young adults' representational competence, and prospects for developing it, in the context of authentic science news reporting. More specifically, the study answers three empirical research questions: (1) What kinds of representational tools do young adults use in the context of their first experiences with infographic-based science news reporting, and with what semiotic richness? (2) What factors do students consider in determining representational adequacy in the context of providing peer feedback on draft versions of infographics? (3) How does students' feedback compare to an expert's feedback on representational adequacy? In addition, we present a descriptive case that takes the above results into account and responds to the learning design question: 'How can science news reporting be organised in classrooms to build on students' representational competence?'

Representational competence and science literacy

Lemke (1998a) identified two aspects of science literacy: The first is understanding science-related concepts and facts; the second is the ability to understand and use the 'complex representational apparatus of scientific reasoning, calculation, and practice' (p. 247). The need for developing students' representational competence in science literacy is necessitated by the complex nature of the science curriculum and the need to use broader 'language' to understand and explain scientific phenomenon in everyday life (Gilbert, 2008; Latour, 1986). Accordingly, researchers in science education consider 'language' broadly to include visual inscriptions and argue that language literacy and science literacy can complement each other and students can be supported to develop both simultaneously (Lemke, 1998a; Tang, Delgado, & Moje, 2014; Trumbo, 1999; Yore & Hand, 2010). Developing young adults' representational competence helps learners to better understand and communicate science and mathematical ideas (diSessa, 2004), foster their inventive capabilities and engagement in learning more about a topic (Azevedo, 2000; Van Meter & Garner, 2005), and improve their ability to relate internal (mental) and external (written) (Zhang, 1997) as well as qualitative and quantitative (Jonassen, 2003) representations in problem solving and analysis.

Students' active engagement in constructing can enrich their scientific vision (Lemke, 1998b). Science textbooks and publications in scientific journals often contain more than one visual inscription per page (Bowen & Roth, 2002). By using these inscriptions, students not only get familiar with the tools of science but they also develop holistic view of scientific phenomena they are studying. Goodwin (1994) framed representational skills as necessary components of professional competence. He argued that drawing and graphic representations are elements of 'discursive practices' that members of a given profession use in crafting and shaping knowledge in a way that is different from members of other professions.

When constructed by students, visually rich representations such as infographics also serve epistemological purposes by fostering constructivist orientations about learning and knowledge (diSessa, Hammer, Sherin, & Kolpakowski, 1991; Lemke, 1998a). Not only students come up with new inscriptional tools, thereby developing their creativity about representations (Azevedo, 2000), but they also consider learning as a constructive process that refines over time as opposed to considering it as a passive process of simply receiving information from a knowledgeable other. This allows students to view learning as a continuous process of interaction between understanding and representation, thereby progressively refining both their knowledge of the subject and their representational competence (Enyedy, 2005). In this process, multimodal representations become essential 'tools for meaning making and knowledge production' (Prain & Waldrip, 2010, p. 1). Similarly, Lemke (1998b) considers meaning-making as a 'material process' facilitated by the practice of using social semiotics. Lemke (1998b) observed that research and practice in the natural sciences is essentially 'a discourse about the materiality of the world' and representations about these material interactions between humans and the environment have increasingly incorporated non-text inscriptions.

Research on representations and learning

Broadly speaking, the trajectory of research on visual representations and students' learning can be presented in a four-level continuum ranging from feature-oriented to student agency-oriented. This grouping is based on the perspective they emphasise and the extent to which learner agency is investigated, with the higher levels including greater student agency. The first level constitutes studies that focused on understanding the types, features and prevalence of representations, often included as a supplement to text-based descriptions, and the instructional purposes they could possibly serve (e.g. Hegarty, Carpenter, & Just, 1991; Lee, 2010; Pozzer & Roth, 2003). Such studies are based on analysis of textbooks or related instructional materials in terms of the types and frequency of representations included and how the visual representations serve as distractive or learning resources for students. Findings of such studies provide insight about choice of representations in preparing textbooks and other related curriculum materials.

The second level of studies focus on understanding the challenges students at different grade levels encounter when learning from visual representations (e.g. Bowen & Roth, 2002; Colin, Chauvet, & Viennot, 2002). Bowen and Roth (2002) provided four college graduates with a 'plant distribution graph' from a university course on ecology and asked them to express their understanding of the representations. The researchers reported that participants encountered 'interpretive difficulties', including understanding the labels on the graph. In the third level of the continuum are studies that examine the affordances of different representations for students' learning of a given topic as well as for enhancing high-level cognitive activities in the learning process (e.g. Cromley, Snyder-Hogan, & Luciw-Dubas, 2010). Studies in this group use static representations and simulations to understand how various features of the representation facilitate or constrain students' learning of a given topic. Cromley et al. (2010) examined undergraduate students' learning strategies from text versus from diagrams. Using a think-aloud protocol and pre-post design, the study reported that students mostly skip or spend less time reading diagrams; however, when they spend enough time reading the diagrams, they use higher level cognitive activities such as choosing learning strategies and making inferences. A logical inference from this study is that students skip reading visual representations because they lack the competencies to understand but reading the diagrams facilitates their learning of the subject.

What all of the above groups of studies have in common is that they use expert-generated representations as opposed to student-generated ones and, oftentimes, on how students learn *from* rather than *with* representations. The fourth level consists of studies that focus on developing learners' representational competence through engaging them actively in the construction of representations (e.g. Azevedo, 2000; Danish & Phelps, 2011; diSessa, 2004; diSessa & Sherin, 2000; Stieff, 2011; Waldrip, Prain, & Carolan, 2010). This line of research has increased over the last 15 years. The *Journal of Mathematical Behavior* (2000, volume 19, issue 4) and *Research in Science Education* (2010, Volume 40, issue 1) have dedicated entire special issues to articles on student-generated representations. Researchers used, to good effect, student-generated representations as tools for developing subject matter understanding in various disciplines, including middle-school science (Waldrip et al., 2010), chemistry (Hand & Choi, 2010; Stieff, 2011), and physics (Hubber, Tytler, & Haslam, 2010).

These studies fostered and examined students' abilities to represent specific topics or ideas such as force (Hubber et al., 2010), solid particles (Waldrip et al., 2010), and macroscopic/microscopic pictures of water (Stieff, 2011), rather than combining different representations in order to communicate a coherent data-driven argument. Our study extends the existing literature in terms of both context and nature of representations. The context of the study was general science literacy. Thus, we focused on students' ability to construct and communicate different aspects of a general science topic in visual forms. The nature of representations is also different in that students used various forms of representations in one infographic. Science news and publications, especially in the public media, use a combination of various forms of representations and often present complex ideas. When representing complex arguments or reading one from a published outlet, students experience various challenges, including choice of representational tools and determining representational adequacy (Schnotz, 2002; Stieff, 2011).

In this paper, we build on diSessa and Sherin's (2000) idea of representational competence that focuses on developing students' understanding and representation of scientific concepts with the practice of learning about their environment and reporting infographic-based science news for online publication. This is a practice-oriented approach for using multiple representations as means of developing scientific arguments using complex infographics. Studies suggest developing students' representational competence is better achieved through designing learning environments that pay attention to cultivating students' constructive resources, engaging students in active inquiry and knowledge construction processes, and providing progressive feedback to help them refine both their understanding and their representations (diSessa, 2004; Enyedy, 2005; Lunsford, Melear, Roth, Perkins, & Hickok, 2007).

Project context and participants

Collaborative Infographics for Science Literacy (CISL) is a design-based research project, funded by the National Science Foundation (NSF), geared towards fostering high school students' engagement in science literacy through collaboratively designing and critiquing infographics on science-related topics. In this process, students produce multipart science news infographics, give and receive feedback, iterate through multiple revisions, and ultimately submit their work to an external editor to be considered for publication in Scijourner (scijourner.org), an online science news magazine with a large circulation of teen readers.

Participants in this study were 71 students in grades 9–12 (46 females and 25 males, ages 14–17) in a suburban public high school with socioeconomically and ethnically diverse population in a large metropolitan area in the Midwestern United States. The school funded a one-to-one student-computer programme in which each student received an Apple MacBook. The teacher (Mr. Rob Lamb), a member of the research and development team with a B.Sc. in Biology and more than 10 years of teaching experience, integrated the infographic project in 3 sections of his general chemistry class, holding sessions once a week for the duration of the semester, each session lasting for about 50 minutes. Importantly, the use of infographics in this class was not limited to any one topic or discipline; the topics and approaches covered by the teacher and students went beyond chemistry and included a number of science domains (astronomy, biology, health and medicine, earth and environmental sciences, physics, and chemistry). Another research team member, Dr. Alan Newman, served as an external editor providing feedback for students, and is managing editor of the online science news magazine. Dr. Newman] is a former research professor with a Ph.D. in chemistry and more than 18 years of experience as science news editor for the American Chemical Society. There was minimal direct instruction concerning representations.

Learning activities were designed and implemented in three phases across the semester. The first was *understanding and describing existing infographics*. This activity related to describing and learning from infographics that were obtained from Internet sources. The teacher selected three infographics developed by professional designers and asked students to work on a series of discussion and description of each infographic in groups of three or four. For each infographic, students first discussed the infographic and produced a two-sentence (15-word) description, and shared their description to the class. Each group then refined the wording and constructed a seven-word, single-sentence description. In the final round, students were asked to describe the infographics using only two words, which could also serve as 'search terms' to retrieve that specific infographic from the Internet. The exercise was intended to provide students with an opportunity to collaboratively critique and make sense of the infographics, and to progressively refine and minimise textual representations in infographic design. The second learning activity was *adding representations to existing infographics*. This exercise involved students adding one or more new representations to an existing infographic. This has some similarity to traditional apprenticeship learning where, for instance, apprentice tailors are asked first to put the finishing touches on pants, rather than starting from the beginning (Lave & Wenger, 1991). In this instance, the teacher provided students with a paper copy of a 'solar system' infographic he created together with a table of data about each planet such as mass, diameter, gravity, length of day, distance from the sun, number of moons, and much more. Students then worked in groups on selecting one or more dimensions of the data in the table, developing an idea for a visual representation of the data and then drawing it in as an addition to the teacher-created infographic. The purpose was to enhance students' visual thinking, choice of representations, and creativity.

The third and the main learning activity involved an *infographic creation project*. Following introductory activities mentioned above, students worked alone or in pairs on creating science infographics. These projects involved choosing a science-related topic, collecting data from publicly available sources (mainly using the Internet), determining credibility and relevance of the qualitative and quantitative data, organising the data and creating infographics, giving and receiving feedback, and revising the infographic for possible online publication. The teacher and the external editor supported students in choosing and refining their topics, determining the scope of their project, identifying possible sources and contextualising the project in their lives. Students used websites (e.g. Mayo Clinic) and online databases (e.g. the Centers for Disease Control) during data gathering, Apple Numbers for organising and visualising quantitative data, Apple Pages for further visualisation and layout of multiple representations, and VoiceThread for providing feedback. The editor provided feedback using Adobe Acrobat Professional's note tool. During the peer feedback, students served as test audience for their classmates and provided constructive comments. The external editor was source of 'expert comment' for both content and design-related issues.

The project data consists of classroom observations, documentation of feedback exchanges, and student-produced infographics from 2012 to 2013. Students worked individually or in pairs on the infographics, and each student or pair submitted at least two versions of their infographic, a draft version and a final version, for a total of 93 infographic artefacts. The first author attended a total of 24 infographic sessions in the three sections, taking field notes on classroom processes, participating in discussions, and prompting students to reflect upon their choice of topics and representations.

Analysis and findings

In this section, we present findings related to variations of student-generated representations, dimensionality of their representations, and aspects of representational adequacy. We also describe a case that models design of infographic-based learning environments in the classroom. Each subsection used different type of data, thus data analysis techniques are described under each subsection.

Representational variations

We analysed the final version of student-generated infographics ($N = 46$) in terms of the types of representations students used. We coded non-text representations into three groups: iconic/symbolic, schematic, and charts/graphs. Iconic representations use images that have physical resemblance with the referent (Lemke, 1998a; O'Grady &

O'Grady, 2008). Images used on public bathroom doors and visualisations used in flight safety instruction manuals are examples of iconic representations that maintain the physical structure of the object they represent. Symbolic representations are more abstract visualisations that use agreed upon symbols to 'represent things that do not have physical form' (O'Grady & O'Grady, 2008, p. 93). Examples of symbols include 'no parking' sign, international symbols for biohazard, and the red ribbon symbol for HIV/AIDS. Schematic representations are used to identify components and represent relationships, hierarchies, and flow of processes. Organisational charts and flowchart diagrams constitute good examples of schematic representations. Charts/graphs are mainly constructed based on quantitative data and present or concretise abstract data. This category included different kinds of quantitative representations such as line graphs, bar graphs, pie/doughnut charts, pictographs (repeated icons used to represent quantities), tables, and bubble charts.

Results showed students are able to come up with different kinds of representations when producing infographic-based science news reporting. The results also revealed the predominance of certain kinds of inscriptions in the students' representational repertoire. Of the 46 infographics, 43 (93%) have 2 or more types of non-text representations indicating the constructive resources young adults have when it comes to using multiple representations. Of these 43 infographics, 26 have 2 types, 11 have 3 types, 5 have 4 types, and 1 has 5 types of representations. Only four of the total infographics have just one type of representation. Table 1 summarises the number and types of student-generated representations.

Results also showed that iconic representations were predominant in student-generated infographics. In 40 of the 46 infographics (87%), students used iconic representations to 'contextualise' their understanding of a topic and communicate to possible readers. Such inscriptions primarily use pictures or drawings that have direct structural associations with the represented phenomenon. Students used icons to serve different purposes, which can be considered in a continuum. At one end, students used icons as a general index to the topic, as simple depiction of an object that they think is related to the topic of their infographic or any of its aspects. For example, a student used the steaming cup in Figure 1(a) as part of an infographic on 'effects of caffeine'. This icon does not add much to a reader's understanding of the effects of coffee, nor does it serve any interpretive purpose beyond indexing the topic; in other words, it is used simply to 'activate' the

Table 1. Types and frequency of student-generated representations.

	Representations	Frequency
Number of representations	One	3
	Two	26
	Three	11
	Four	5
	Five	1
Types of representations	Icons/symbols	40
	Schematic	8
	Graphs/charts	33
Types of graphs/charts	Pie/doughnut/bubble	23
	Bar	14
	Pictograph	7
	Line	5
	Logarithmic scale	1

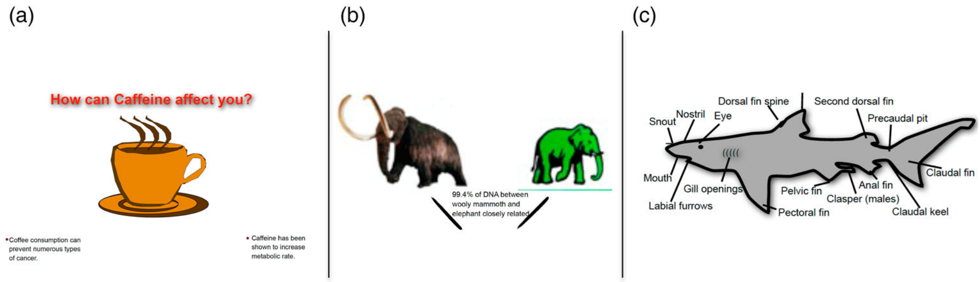

Figure 1. (a) Caffeine effects: icon for depiction. (b). Cloning: icons (animals) for comparison. (c). Shark attacks: top icon for illustration.

memory of drinking coffee in the mind of the reader or to instantiate possible sources of caffeine. The second way students used icons was for presenting and communicating comparative information. In Figure 1(b), a student working on 'cloning' used pictures of an elephant and a woolly mammoth to depict the animals and described how their DNA is similar using text. The use of the icon is still depictive in nature but such use involves two or more icons with the purpose of comparing the referent. The third way of using icons is illustrative in purpose. This is when students use drawings to identify various parts of an object. Figure 1(c), where students drew and point out the anatomy of a shark is an example of using icons for illustrative purposes. Each of these ways of using icons can be considered a visual language for certain kinds of propositions. Depiction indicates simple *relation* to the rest of what is in the infographic. Comparison indicates a proposition that two specific concepts are related in specific ways, which may be clarified by text labels or other visual conventions. And illustration indicates a proposition that important aspects of the structure are marked or indicated.

The second type of representation students used in creating science news infographics was schematic representations. All in all, eight infographics have schematic representations. A student constructed the infographic shown in Figure 2(a) that depicts the processes involved in cloning. Similarly, another student who was a wrestler with personal experience of cauliflower ear constructed the infographic shown in Figure 2(b) to represent the progression of the problem when encountered and the available options to handle it (the series of green arrows on the left represents the student's suggested ideal path for a patient, whereas the red arrows on the right are a less optimal sequence).

The third category of representations is graphs and charts. Students used graphs/charts to concretise and represent abstract quantitative data. Figure 3(a,b) show examples of such representations. Figure 3(a) presents fast food and restaurants in terms of nutritional values. Figure 3(b) is about snake venom. We observed two important issues while analysing students' use of quantitative inscriptions. The first was the predominance of pie and doughnut charts in students' quantitative representations. As noted above, of the total 33 infographics that contain graphs/charts representing quantitative data, 23 have a pie/doughnut chart as the main representation, 14 have bar graph, 7 used pictograph, 5 used line graph, and 1 used a logarithmic scale. Our classroom observation and the feedback from the classroom teacher also confirms students' general tendency to start their infographic with pie charts. In some cases, students use pie chart even when they are not representing proportions of a meaningful whole. The second issue was the ability of

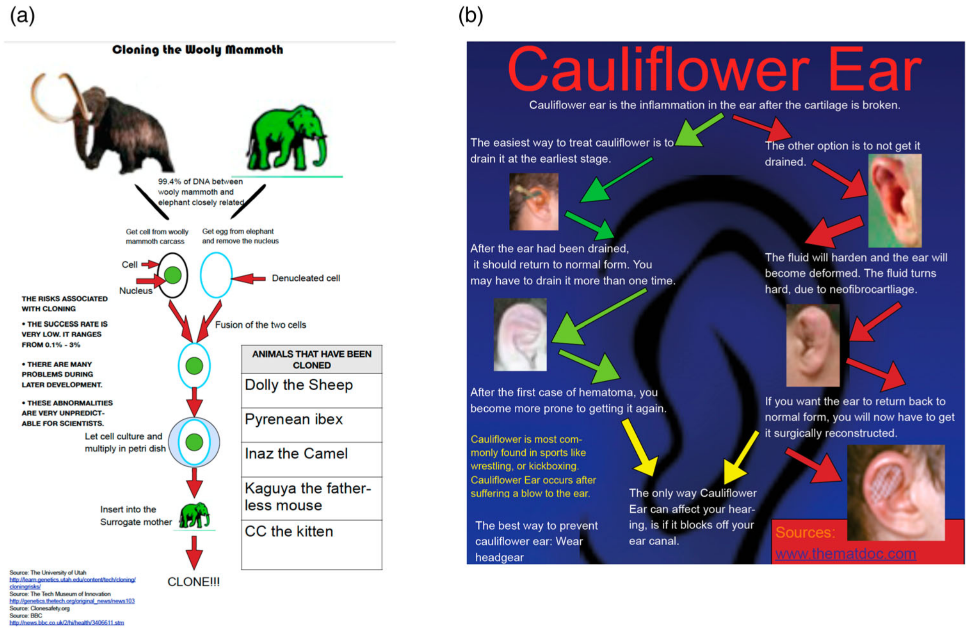

Figure 2. (a) Cloning the woolly mammoth. (b). Cauliflower ear.

some students' to combine learned representations such as graphs with inventive (often qualitative) representations while presenting quantitative data. This is a variation of charts but with embedded qualitative cues. Figure 3(b) presents an example of such embedded representation. In this infographic, two students working on a 'Snake Venom' infographic wanted to represent four snakes in the order of how dangerous their venom is for humans – thus, they scaled the length of each snake to how dangerous its venom is.

In the case of a bar chart, the correspondence is between the length of the bar and the number associated to it. What is added in this embedded representation is the qualitative, indexical correspondence between the inscription and the represented phenomenon (e.g.

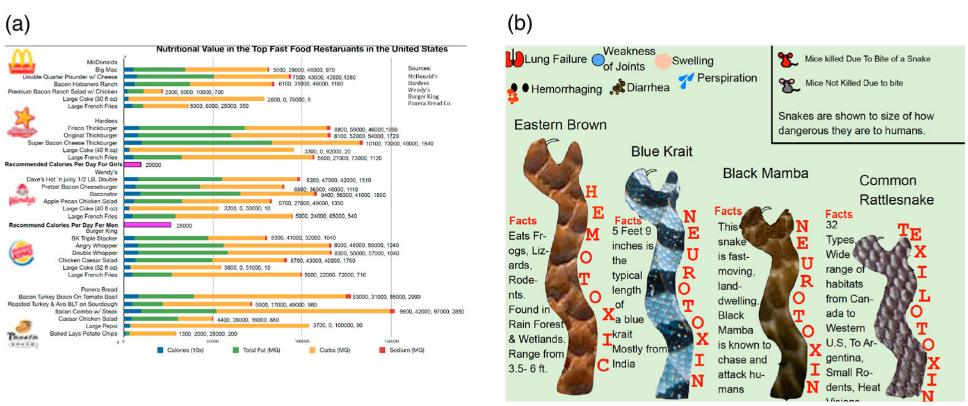

Figure 3. (a) Comparison of fast food (restaurants). (b) Dangers of snake venom.

snake) while maintaining the quantitative feature of the data. Such a combination shows the students' level of creativity and the complexity of students' inscriptional repertoire. At the same time, such inscriptions can provide readers with richer insights.

Dimensionality of representations: a metric for semiotic richness

An important issue in analysing visual representations such as infographics is determining the communicative function of each type of representation. Given that most infographics contain multiple representations, what purpose does each representation in the infographic serve? Does each type of representation communicate different information or does it repeat the same information? These questions can be answered by determining what message is communicated by each representation in the infographic. For this, we analysed each infographic for the number of dimensions it has which are non-text representations. Dimension, in this case, is an aspect of the represented topic that is communicated by one type of representation. It is about what question does the message in the representation help us to answer about the topic without using repetitive explanatory text. In other words, a dimension tells what each representation contributes to the overall message communicated by the infographic. For example, the infographic on 'shark attacks in the US' (Figure 4) has five dimensions: anatomy of a shark, types of sharks, location information (maps), frequency of shark attack by US State, and comparison of shark attack with other causes of death. This infographic uses four types of non-text representations: icons, maps, a doughnut chart, and a logarithmic scale. The number of dimensions for each student-generated infographic ranges from zero, where the visual representation communicates no additional information that is not already communicated by textual descriptions (or other types of representations such as a table and a graph representing the same data), to as many as five dimensions. It is important to note that one type of representation may communicate zero, one, or more than one dimensions. For example, each representation in Figure 4 communicates one dimension. On the other

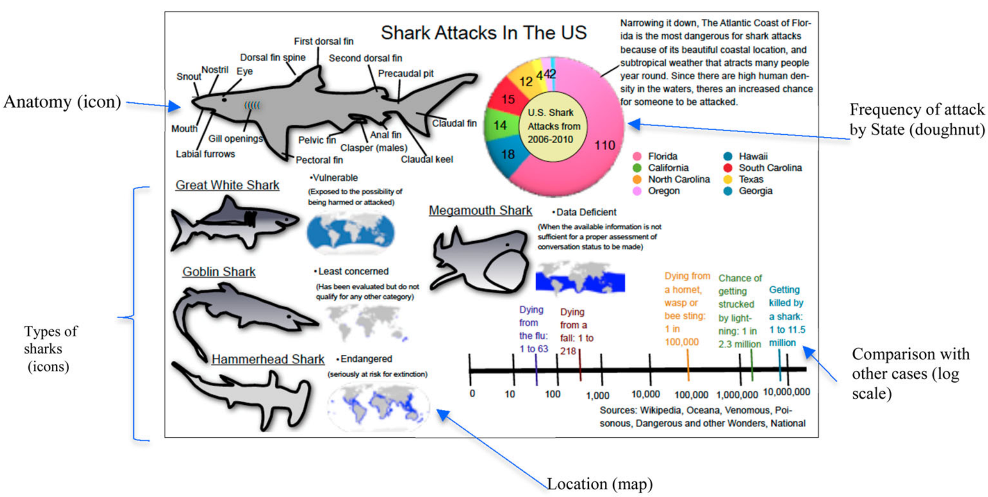

Figure 4. Shark attacks in the US.

hand, the infographic in Figure 3(a) has one type of representation (stacked bar chart) and four dimensions (nutritional value of each serving, comparison between different servings, comparison between restaurants, and comparison with recommended daily calories).

We calculated a dimensionality ratio for each infographic by dividing the number of dimensions from non-text representations by the number of non-text representations in the same infographic. Text was purposefully not counted in this metric, and thus, any dimension from an independent text in any infographic was not considered in the analysis. We believe the dimensionality ratio expresses the semiotic richness and parsimonious nature of infographics students create by showing the degree to which learners communicate 'more with less' and do not overuse non-value adding representations (as Alberto Cairo, 2013 has pointed out, judicious repetition of certain ideas can increase the communicative effectiveness of an infographic, but uniqueness across representations is also required). Accordingly, ratio values of less than 1 imply using representations that do not add meaning to the overall message. An example of this is the coffee cup in Figure 1(a), where no additional information is provided by the icon. If the dimensionality ratio is 1, it means one type of representation in the infographic communicates one dimension of the issue under consideration. A ratio of greater than 1 implies one type of representation provides more than one dimension, thus allowing multiple layers of comparison or insight for readers (e.g. Figures 3(a), which has a dimensionality ratio of 4).

Figure 5 represents how many of the analysed infographics have dimensionality ratios of less than one, one, or more than one. As we can see from Figure 5, 18 (39%) of the infographics have low dimensionality or richness. On the other hand, only 10 (22%) of the infographics have representations that communicate multiple dimensions.

Representational adequacy

Infographics are more than visual representations of data. They include qualitative ideas and serve as means of making data-driven arguments. Thus, it is important that students develop ways of determining the adequacy of representations to serve the intended purpose. Representational adequacy implies the extent to which the infographic is complete enough to communicate the intended message with enough context and information for readers. Participating students were asked to provide feedback on the draft versions of

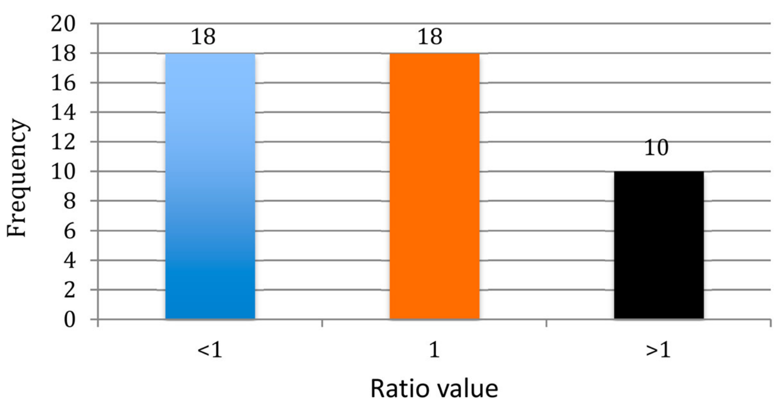

Figure 5. Dimensionality ratio of student-generated infographics.

peer infographics using VoiceThread, an online application for collaborative multimedia commentary. We uploaded all infographics to VoiceThread and created accounts for all students. Students were given access to all of the infographics created by their classmates. Each student then logged into her/his account and provided written feedback to each of their class members' infographic. In addition, the external editor provided feedback for each infographic in .pdf format using the commenting tool built in to Adobe Reader.

We analysed the comments of students and that of the external editor. We extracted students' comments from VoiceThread and segmented each comment into idea units – a sentence, part of a sentence or two or more sentences that represent a given idea. We also extracted and segmented the editor's comments from the.pdf files. We then analysed the two sets of comments separately using open coding with constant comparison method (Strauss & Corbin, 1990). After reading the first segment, we created a provisional category representing what aspect of the infographic the comment refers to. We compared subsequent segments to the provisional category and when we considered it similar in meaning, we coded the segment under the category; when we considered it to be different, we created a new category. We continued this process iteratively, moving between segments, categories, and the infographic about which the comments were provided. Table 2 shows coding examples.

Seven students' comments were excluded from this analysis because of their exclusively affective nature and lack of task specificity (e.g. 'I like your infographic' and 'nice infographic'). There were 916 segments from the students' feedback and 190 segments from the external editor whose comments range from one to nine for each infographic. Figure 6 presents the categories and their relative frequency.

Analysis of the 916 student feedback segments resulted in 9 categories that focused on aspects of science infographics: clarity, completeness, correspondence across parts, design and organisation, language, readability, relevance, representation, and sources/originality. Similar analysis showed that the editor's feedback focused on the same eight categories as the students with the exception of 'readability'. Table 3 presents the meaning and examples of each category.

What we can glean from Figure 6 is that in the context of specific infographics, students were able to determine the adequacy of representations and provide feedback for improvement. When considered collectively, students' comments can serve as aspects of infographics that users and creators such representation need to focus on. It is also important to note that aspects of infographics generated by students were similar to the ones generated from the external editor, but with different priorities. The three most

Table 2. Sample comments and coding.

Comment	Codes
'There is a lot going on, [it] could be more organized'	Organisation
'The key on the bottom of the people could be more organized. *The snakes on the bottom was [sic] a little bit confusing*. **Did you guys draw the mice?**'	Organisation, *Message/Clarity*, **Source/originality**
'These are very great visuals. Did you get permission to use the picture of the fish in the bottom? *The data is clearly described with the thermometer. Very good infographic.* **I would just double check the typing and grammar.**'	Source/originality, *Representation*, **Language**
'Try a bigger font size to see if it is more appealing to the eyes. *The full yellow background is also in dire need of a re-vamp.*'	Readability, *Colour*
'There is a lot going on and it is kind of crammed. So you could possibly take some stuff out or spread things out.'	Design (space)

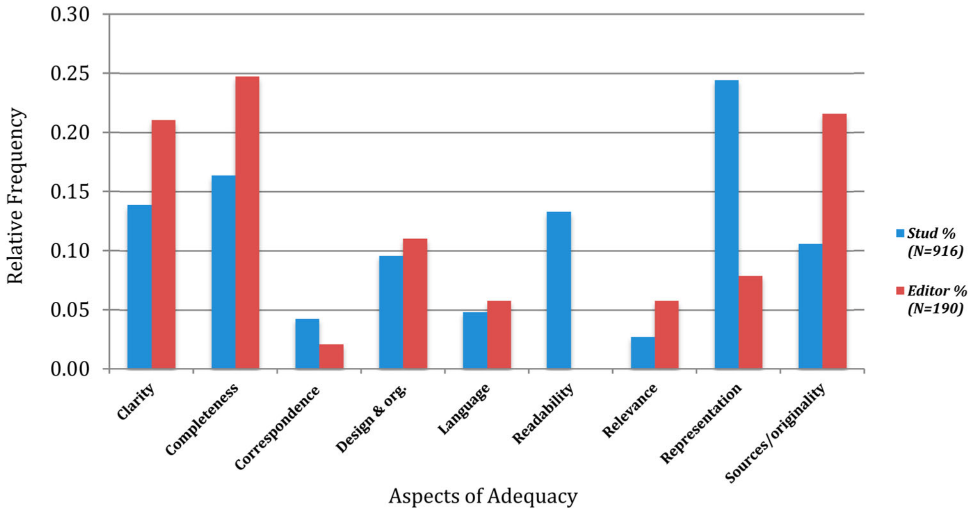

Figure 6. Aspects of representational adequacy.

prevalent categories for the editor were completeness of the information, source/originality, and clarity of communication. For students, however, 'representation' was the most prevalent criterion followed by completeness and clarity. The editor's reasoning was that he intentionally focused his comments on the content aspect of students' infographics first as opposed to the representation aspect like the students. That is, he delayed his representation-related comments until he was satisfied with completeness of the content. Also source/originality, which deals with where the data/representation came from and whether or not the source was credible enough, was second in order of importance for the editor but fifth for the students. Visual representations have a 'wow' factor since they attract attention easily; this can be counterproductive if the source of the data is not credible enough or the accuracy and relevance of the data cannot be justified. Thus, we see that the priorities of an experienced editor are different, but perhaps interacting with that editor could provide productive learning opportunities for students. Accordingly, we now turn to the design of learning environments with these results in mind.

Designing instruction to support development of representational competence

How can we help students to progress from using iconic or depictive representations to using more complex representations that communicate abstract data and ideas? Researchers have suggested considering what students bring to their learning, minimising direct instruction on representations, and using a progressive refinement approach where students improve their understanding and representation over time (Azevedo, 2000; diSessa, 2004; Enyedy, 2005). Similarly, our study showed a feedback-oriented, progressive refinement approach could be effective for helping students in this regard. We present the case of the 'Shark Attack in the US' infographic as an example. We do not claim similar progress happened in all cases of infographics in our exploratory project. Rather, our goal is to present a model where the scope of the project, students' understanding of the topic,

Table 3. Aspects of representational adequacy of science infographics (from students' and editor's comments).

Category	Meaning	Examples (*S = student, E = editor*)
Message/clarity	Clear representation of message and components or lack thereof	'Does this mean that you need to use an elephant cell to clone a woolly mammoth?' (S) 'I have no idea what these 3 graphics mean or what the hammer stuff means. Will your readers understand this?' (E)
Completeness (including data, context/scope, and depth)	The extent to which the infographic has the necessary elements to convey a message comprehensible to an audience. It relates to data, context, and scope/depth	'A statistics [sic] of how many [types of] fish possess this biological antifreeze would be nice' (S) 'Before you break down the numbers, how many people suffer heart disease in the US in one year? How many die? How does it compare to other diseases? You never give us the key numbers. And what goes under the term heart disease?' (E)
Correspondence across parts	The alignment or correspondence between different aspects of the infographic. It includes consistency in using representational tools (e.g. colours, lines, icons) and the extent to which the title of an infographic reflects the message or content included in the body	'This chart is talking about effect of obesity but your title is about how many calories are taken in and burned' (S) 'This is a misleading title. Do nuclear power plants go boom?' (E)
Organisation and design	The layout of the infographic, space utilisation, and ways of organising or arranging data	'A lot of your shapes are covering your paragraphs and descriptions. You should reorganize for a better visual effect' (S) 'Did you ever consider making this a 3-D graph? You could have collapsed this into one graph, females and males shown one behind the other. Plus your current [two] graphs are not really easily comparable because you have different y-axes.' (E)
Language	Use of text in the infographic including the use of jargon, the presence of abbreviations, and grammatical and spelling errors	'There're many terms that could use some defining and explaining. If you don't know bowling too well this infographic could be confusing' (S) 'What is PDD-NOS and the rest? … You are throwing jargon at us; you need to explain it' (E)
Readability	The size and colour of text, the level of contrast between text colours and background colours, or changes to visual representations that will make them more easily decipherable	'Is there any way you can make this more readable and to make the background color pop with the rest of the colors?' (S) 'You can change the size and/or color of the font to make it more readable' (S)
Relevance	The specific value that a certain data or representation contributes to the main argument or topic the infographic communicates	'do the boxes in the middle have a purpose in your infographic?' (S) 'These 2 images add nothing to your infographic. They should go' (E)
Representation	The choice of representational forms (e.g. text, icons, drawings, maps, and lines) and the 'appropriateness' of the chosen form or tool to convey the message	'Can you narrow down on the text? What you did with copper should be enough for the rest of the chemicals.' (S) 'Why not make that table into an infographic? … this should have been expanded with more products and presented as the main infographic.' (E)

(*Continued*)

Table 3. Continued.

Category	Meaning	Examples (*S* = *student, E* = *editor*)
Source/originality	1) Authorship – whether authors have created a given representation or they copied it from a different source and 2) the absence or credibility of a source	'These are very great visuals. Did you get permission to use the picture of the fish in the bottom?' (S) 'Wikipedia is a good place to start but a bad place to end. The data in the wiki came from somewhere else – follow the references' (E)

and the nature of representations changed (to the better) over time as a result of feedback-oriented learning and instruction activities.

The authors were a pair of students. The teacher asked students to first produce an 'infographic benchmark' including a brief description (what and why) of the planned infographic that 'convince[s] [the teacher] that you are creating something others will want to see', possible data sources (up to five websites), and a rough sketch of what the infographic would look like at the conclusion of the project. The students who worked on the shark attack infographic stated their objective as '[drawing] the picture of a shark and pointing out the body parts' and drew the sketch shown in Figure 7. The students' initial idea was to learn about a shark and represent their understanding by drawing its anatomy. After they started working on the project and obtained more information about sharks, one of the students learned that she and her family were going to Florida for a vacation. This prompted her to think about and discuss with her project partner the possibility of shark attacks.

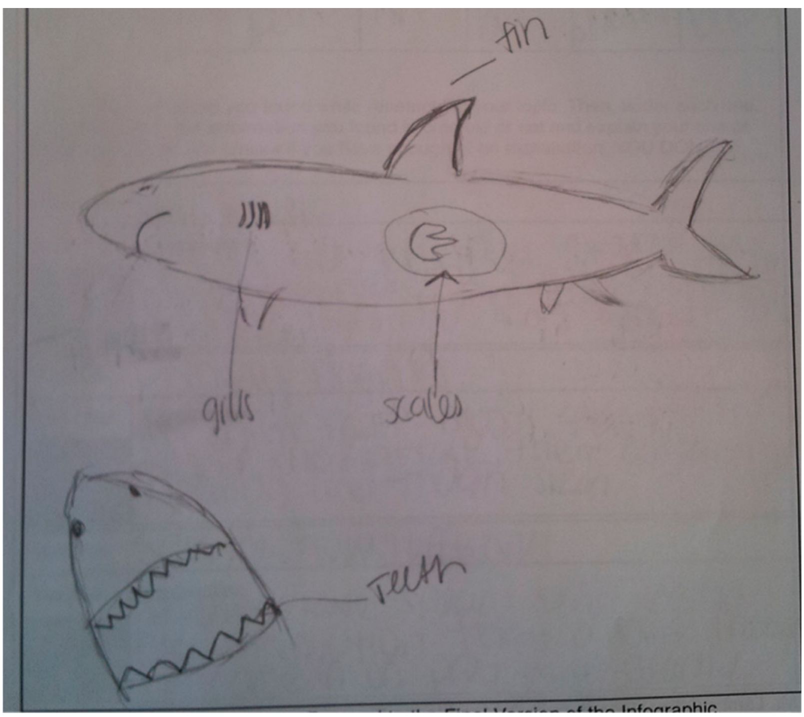

Figure 7. First sketch of 'Shark Attack' infographic.

This resulted in changing the project from ‘anatomy of the shark’ to ‘shark attacks’. The students searched for relevant data, organised it and created the first draft of the infographic shown in Figure 8 (Note: the yellow ‘Sticky Note’ is a comment from the external editor).

A close examination of Figure 8 reveals that students have broadened the scope of their project to include types of sharks, location data, and frequency of shark attack, beyond the original idea of presenting the anatomy of a shark. They also used multiple representations by including a drawing, maps, and a pie chart for representing different kinds of information. The students interpreted the higher frequency of shark attacks in Florida to mean the student had enough reason to worry about in relation to her family’s planned trip. She talked about it often in class.

The student infographic authors did not provide explanation as to why Florida has the highest frequency of cases, but at the same time, the finding had become personally relevant to one of the authors. This absence of explanation could be attributed to either students not seeing the need for putting the data into context and taking it at face value, or students thinking that infographics were all about visual representation and should not include text (they used text as labels only). This is an opportunity for teachers to identify learning gaps and provide feedback for improvement (Hattie & Timperley, 2007). Accordingly, the external editor provided the following comments related to the data and the author’s concern:

> this graph is interesting. Why is FL number one? … Also, why not create a second graph that compares the total number of shark attacks with other things, like numbers struck by lightning, killed by tornadoes, or drowned. That would put the risk in perspective.

The final version of the infographic (presented in Figure 4 above) addressed the editor’s comment and showed improved representation. In this version, the students included two more types of representation: text description and logarithmic scale. In our post-project

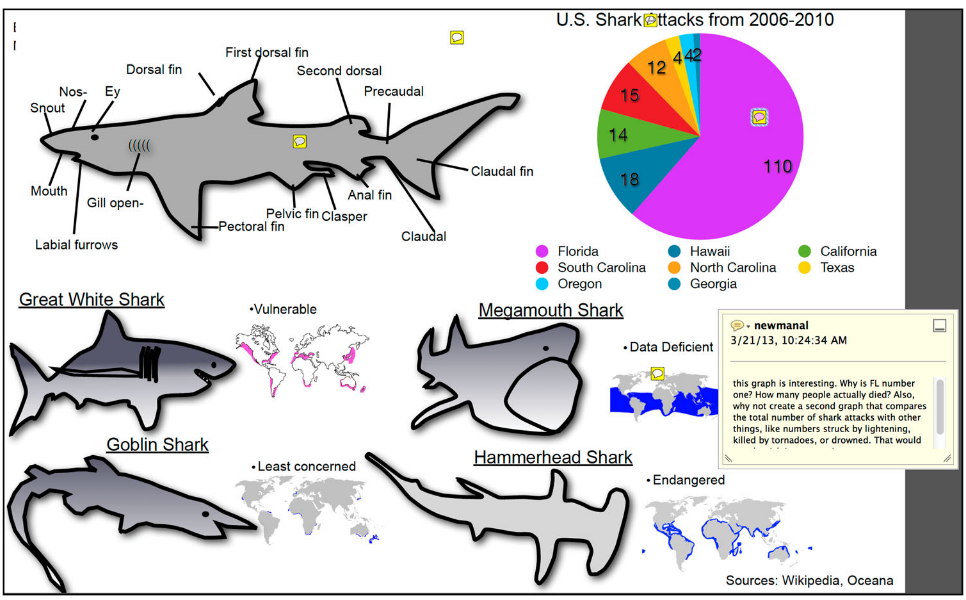

Figure 8. First version of ‘Shark Attacks’ infographic with a sample of the editor’s feedback.

interview, the authors reflected on how working on the revision process helped them to change their perception about shark attacks by saying ' … it is unlikely to get attacked by sharks. I thought people get attacked by sharks all the time. They really don't … you die from the flu more than getting attacked by a shark'.

Discussion and implications

The abundance of data-driven, science infographics in the public media as well as the availability of publicly accessible data affords a good opportunity to develop science literacy among the general public. However, this promise will not be met unless we have instructional strategies to develop young adults' competencies at making sense of or contributing to the multifaceted science news using multiple representations. Studies on secondary school students' use of multiple representations have most often been limited to a context of specific science topics rather than to a broader interdisciplinary domain such as general science literacy. Visual representations are tools to both 'enhance and reduce information', but the pedagogy of developing representational competence is always challenging (Lehrer & Schauble, 2006, p. 375).

The purpose of the empirical research portion of this study was to understand and describe the nature of representational tools secondary school students use when they engage in creating infographic-based, authentic science news for youth readers. We also aimed at determining how participants evaluate the adequacy of infographics by engaging them in peer feedback processes. Students were able to combine and use multiple representations in their infographics as evidenced by the number of infographics with more than one non-text representations. The issue was the nature of these representations. The predominance of iconic/symbolic representations in student-generated infographics (87%) as well as students' tendency to rely on pie/doughnut charts when they see the need for quantitative representations should be a concern for educators as to whether enough emphasis is given to building students' representational competence. This also raises a question about the nature and adequacy of teaching visual representations in secondary science education.

As much as students created various forms of representations in their infographics, we also observed that it was not easy for them to think visually and represent the data they gathered in visual forms. The first visual representation many students gravitated to was either a pie chart or iconic representation that resembles the represented phenomenon. Reed (2010) attributed such problems to lack of instruction on visual thinking. Reed argued that despite teaching language arts, secondary schools do not teach visual thinking. In his analysis of the nature and trend of visual representations in 34 middle-school science textbooks in the US, Lee (2010) reported that high-fidelity, photographic images with minimal instructional purposes are increasingly replacing schematic and abstract representations. It is logical to assume that students might be replicating what they see in their textbooks. It could also be the case that students are often expected to understand and learn from expert-generated representations in textbooks as opposed to constructing and learning with representations.

The fact that students were able to provide meaningful comments related to representational adequacy and that their comments were in nearly the same categories as the comments of the external editor (an expert) is explained by the critical nature of their capabilities (diSessa, 2002). diSessa (2002) differentiated learner's 'constructive resources'

– native representational repertoire students possess, from their 'critical capabilities' – their ability to determine effectiveness or adequacy of representations (p. 107). diSessa argued that learners' competence about representations, especially in the beginning, is more reactive in nature to the extent that their construction of representations is influenced by a 'strong sense of better and wrong representations' (diSessa, 2002, p. 107). Their competence is better displayed in the context of critically appraising specific representations. Students find it challenging to come up with a list of criteria to determine adequacy in the absence of specific infographics to assess.

Infographics can be misleading in that authors could unduly emphasise certain aspects by working on visual appeal rather than by providing accurate data and credible sources. The difference in priorities of students (compared to the editor's comments) and the lesser emphasis students gave to 'completeness' and 'source/originality' could mean that either students were not able to determine the relevance of science information and put it into a larger context or they were persuaded by the colours and forms of representation rather than by their substantive contribution (Ryoo & Linn, 2014). In either case, students need more support if they are to make good use of learning with and from representations. Prior research from our project that focused on the production of text-based news stories showed that teachers, too, differed in important ways from the editor in the nature of the feedback they initially provided. At the beginning of participation in the predecessor to this project, Polman (2012) found that teachers provided more form edits than the editor, and the editor provided more content edits.

Our hope is that the above empirical findings on students incoming proclivities and assets as well as their limitations can be capitalised on within the model of multiple and varied opportunities for students to receive feedback that was presented in the 'Shark Attacks' case. We aim to enhance the quality of guidance that future students doing science news reporting with infographics receive in curricular resources and from their teachers. We also are using these results to enhance the quality of rich and varied feedback that learners receive from not only their teachers, but also their peers, and from external audiences such as our newsmagazine's editor.

In recent years, visual representation is considered as an 'emerging field of practice and inquiry' in the domain of science education (Gilbert, 2008, p. 3). This study framed infographics as learning tools to develop learners' skills at using multiple representations in the context of science literacy. The aspects of representational adequacy that emerged from analysis of students' and the editor feedback have informed our design of curricular resources and professional development in our subsequent project. These categories can be used as resources for teachers and students who use infographics in particular, and visual representation in general.

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