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Exploring Network Visualization of Data in Elementary Classrooms

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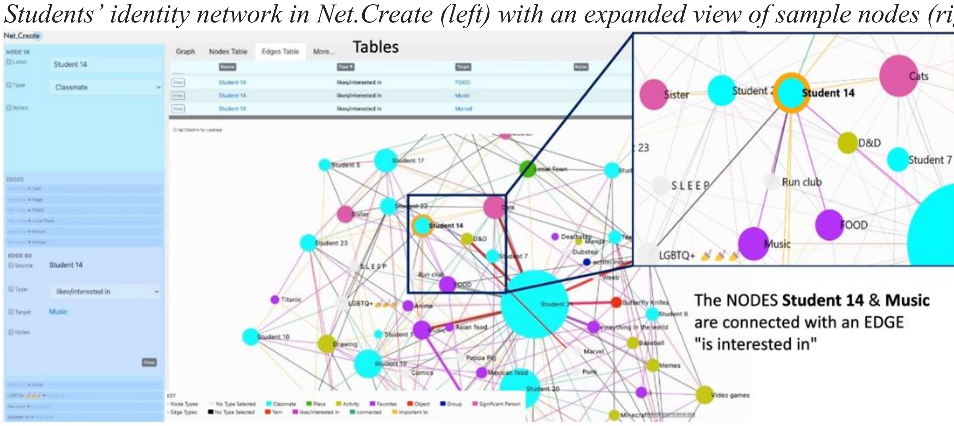
Abstract: This study aims to understand how elementary students can reason about data and data visualization through participation in thematic network visualization activities that integrate locally relevant, personally meaningful data. Young students constantly struggle to focus beyond individual data points to comprehend the overall trend for a complete dataset (Rubin, 2020). This study describes the design of a curriculum unit that incorporates a series of network visualization activities as building blocks to develop students' reasoning skills on aggregate patterns of the entire dataset. Our analysis draws on Cultural Historical Activity Theory (Engeström, 1999) to identify mediators within four network visualization activities and explicate how they transformed students' progressive understanding of the aggregate dataset they were exploring to make inferences.

Introduction

In an era of data deluge, the general public has more access to a massive amount of data and more opportunities to engage in data reasoning activities than ever before. Therefore, learning scientists have intensified efforts to prepare students for working with this kind of data in personally meaningful contexts (Rubin, 2020) and advocated for further strengthening young students' data reasoning abilities to support future learning (Jiang et al., 2022).

Fundamental data literacy activities include data collection, management, analysis, and interpretation using data visualization tools (Rubin, 2020). The expert's viewpoint on data exhibits a fluid and flexible switching between local and global observations (Ben-Zvi & Arcavi, 2001). Local data observation refers to a focus on individual data points, whereas global observations include summarizing the overall pattern of the entire dataset and making inferences from the patterns. This global observation serves as the foundation for the identification of broad patterns within the data. For example, to recognize specific data points as outliers, it is necessary to consider how they relate to other data values from a distributed perspective. However, young students frequently struggle to move beyond individual data points and find it difficult to reason about the overall dataset patterns, leading this to be a perennial barrier in data literacy education efforts (Rubin, 2020).

Figure 1
Students' identity network in Net.Create (left) with an expanded view of sample nodes (right)



Visualization tools can be vital to support students' reasoning with data; for example, CODAP (Hardy et al., 2020) and TinkerPlots (Rubin & Morkros, 2018) support learners in viewing different data graphs and answering relevant data questions. The present study utilizes Net.Create (Craig et al., 2021), an open-source network visualization tool that enables multiple users to intuitively co-construct and co-revise network datasets. It has previously been successfully implemented in undergraduate-level humanities classrooms to engage students in sensemaking about historical figures, events, and their relationships with each other (Craig et al., 2021). Net.Create allows students to work on a collective network simultaneously by creating nodes of various types and linking each node via different kinds of edges. A node is a circle typically representing a person, place, thing, or event. Figure 1 depicts one Net.Create network used in the present study, illustrating students' collective identity in the form of interests, experiences, and connections to each other. The nodes represent individual students, hobbies, or locations, and the edges (lines between them) represent relationships such as "likes/interested in." Net.Create, like other network visualizations, can automatically adjust the size and positions of each node and edge based on how many connections a node has to other nodes. Node size is determined by the number of connections to other nodes, a value often labeled as degree centrality. By visualizing this as the size of the node, network visualizations show the relative importance of the influence of the individual nodes in the network. Users can further explore the influence of a node by manipulating the network physically, as larger nodes have more "gravity" and thus pull smaller nodes along. An edge's thickness also communicates the number of connections between two specific nodes and may therefore indicate the impact of these relationships. In addition to the network representation, Net.Create includes other interconnected data displays (e.g., tables) to support students' data reasoning across those displays (see Figure 1, top middle). Although the affordances of visualization tools support data exploration and interpretation, students need an entry point to engage productively with visualizations (Roberts & Lyons, 2020). Therefore, we designed a series of network visualization activities to mediate students' data reasoning and interpretation as part of the present study. The present paper includes an analysis of this sequence to better understand how learners engage with the range of tasks and networks. We specifically aim to answer: how do different ways of mediating students' exploration of network visualizations affect their reasoning about network datasets?

Theoretical framework

Our work is grounded in Cultural Historical Activity Theory, or CHAT (Engeström, 1999), and particularly takes up the notion of mediation to examine how different network activities transform students' emergent understanding. Mediation (Vygotsky, 1978) is the idea that activities, including learning, are transformed by other elements of the social and cultural environment (Danish, 2014). These elements or mediators include tools, community, rules, and the division of labor that shape learners' activity as they pursue a shared goal, often referred to as the object of activity (Engeström, 1999). The present study examines four network activities (Table 1) with objects ranging from creating/modifying networks to making inferences from pre-built networks. In each activity, our analysis focuses on how individual students (subjects) participate in the creation, modification, or analysis of network visualizations (tools) in different group settings (a division of labor). Their participation is also regulated by the classroom *norms and rules* of each activity.

Design

This study is housed within a larger project called Visualizing Funds of Identity (VFOI), which intends to leverage network visualization tools to help students understand more about themselves and their community as well as to hone their fundamental data literacy skills (Stiso et al., 2023). The entire curriculum spanned six forty-minute class sessions designed to engage students in a cycle of creating, modifying, and exploring network visualizations of different topics. Those topics were co-designed with one classroom teacher and utilized class-based projects and a board game format in order to display network values in locally and personally meaningful ways. The present study focuses on the ways that two physical networks and three digital networks mediated elementary students' progressive data literacy skills. See Table 1 for a summary of the four network activities.

Table 1
A Summary of the four network activities

Topic	Format	Summary
Collective identity	Yarn network	Icebreaker to explore how a network represents people and relationships
Collective identity	Net.Create	Use Net.Create to learn basic network terms, how to create a network, and the value of network visualization compared to the yarn network
Chicken industry	Net.Create	Explore the meaning of sizes (node & edge) in a network visualization for a real-world context
Social media marketing	Net.Create and board game	Apply meanings of sizes and types of nodes and edges to a real-world context

Data sources and analysis

Twenty-three fifth and sixth-grade students from the Midwestern United States participated in this study, and seventeen of them completed both the pre-and post-tests. This analysis examined what students learned from their performance on the pre/post-test and their in-situ understanding that emerged through classroom activity mediation. The pre/post-test contains seventeen open-ended questions aimed at evaluating students' grasp of a range of practices of network visualization and data literacy. The authors iteratively developed and refined qualitative characterizations of students' understanding of the key concepts explored in their answers during the pre/posttests with a focus on data literacy concepts that were used to identify patterns in students' understanding. The classroom video data analysis began with reviewing and content logging students' recaps and debriefs of each activity across the six days of implementation. The present analysis focuses on four network activities, selected to provide a rich contrast regarding how the different modalities support a wide range of network utilization and, thus, aim to represent the potential of these kinds of activities rather than every single moment from the present study. Finally, all authors performed Interaction Analysis (Jordan & Henderson, 1995) to determine how students' understanding arises across those network activities and mediators that supported their emergent understanding through iterations of collaborative data sessions.

Findings

Pre/post tests

Analysis of these tests shows that students improved their understanding of what a network is, particularly how networks are made up of nodes and edges and their ability to interpret network visualization as a means of making sense of the underlying data represented within it. Findings also indicate that students began to recognize the practical uses of networks in real-world contexts. Students' explanations about networks shifted from vague references to a network as "a thing on the internet" to more robust technical definitions such as "a network is usually something online that shows how people might be connected to certain things." Students' interpretations of the network moved from initially describing details depicted in individual nodes (e.g., video games, Minecraft) to indicating a rich appreciation of the relationships between multiple nodes within the network. For example, ten students indicated their awareness of connections within the network in the post-test, while one student did in the pre-test. In addition, nine students appreciated the utility of networks as a way "to get to know each other better/ people's like and dislike." While not all students completed the post-test worksheet due to the number of questions, we view these results as quite promising, especially given how the network activities also helped students to explore key ideas of interest to the classroom and teachers, such as how the chicken farming industry works (see below).

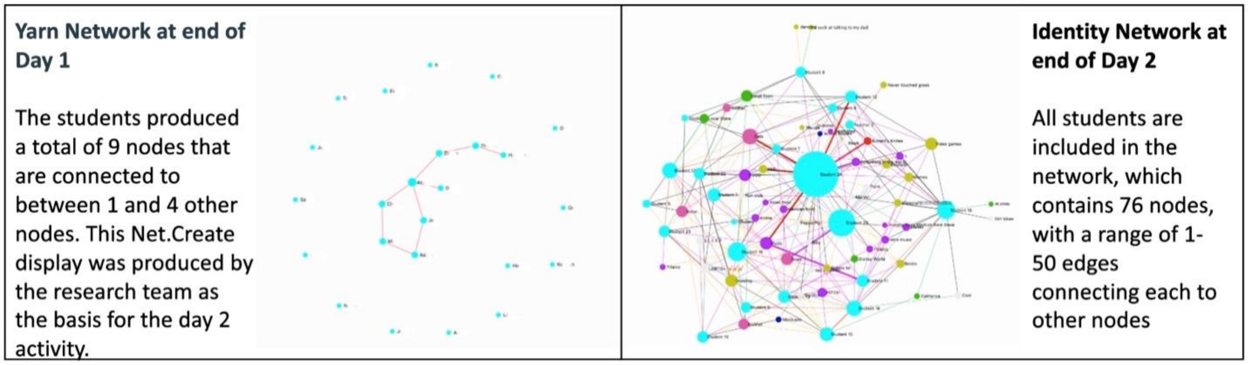
Three cases

The three cases below were chosen from the four network visualization activities in which students participated in the exploration, comprehension, and utilization of network datasets. Select deidentified example networks can be seen at: http://theraptlab.org/projects/netcreate_examples. For each activity, we iteratively reviewed the classroom video data, discussing as a team what we felt was the most salient mediator within each episode. We then conducted Interaction Analysis (Jordan & Henderson, 1995) to explore how the salient mediators appeared to influence the students' activity. Case one depicts two network activities from the first two days of the intervention in which students first built a physical yarn network of their interests and then expanded that network within the Net.Create software. Here, we examined how the community and network tools in the activity functioned to enhance students' awareness of their connections. In case two, students' prior knowledge and the teacher's facilitation mediated their exploration of a pre-made network visualization of how the chicken farming industry works, a topic chosen to complement a semester-long cross-curriculum project the teachers had previously planned, which will involve the students in researching various locally relevant farming industries. Case three depicts an activity from day 5 where students' explorations of how marketing may work in social media websites were mediated by their emergent understanding of networks, the activity rules, and the facilitators.

Case1: Starting to explore the classroom as a network

Students constructed a physical yarn network as the opening activity of the implementation. In this activity, each student acted as a node (representing themselves) and was connected to peers who had overlapping interests or experiences using yarn (tool) that was strung between them on the floor. To create the network, we developed eight questions (tools) based on the Funds of Identity literature (Esteban-Guitart & Moll, 2014) to prompt students to share their own experiences and stories (rule). Sample questions included "name a place that is important to you?" and "what is an activity or hobby you enjoy?" Initially, none of the students were connected. The first student then selected a question from the list and shared an answer as well as an elaboration (rule). Next, any peers who felt they had a similar experience would raise their hand (a division of labor), and the first student would pick one to "connect" to, passing them the ball of yarn. This next student often explained their connection to the student who passed them the yarn, they would then select a new question, and the process continued.

Figure 2
Students' yarn activity on day 1 (Left). A complete identity network (Right)



This yarn activity led students to tell elaborated stories about themselves and their families, many of which were previously unknown to the teachers and the class. We see this in class debriefs in which many of them indicated that they had learned something new about one another. For example, one student shared that her mother was from Ireland, which surprised the teacher, who exclaimed, "I cannot wait to hear the story." The teacher (community) asked follow-up questions which served to mediate the students' description, leading them to share an anecdote about how the mother's Irish accent perplexed family members. In addition to prompting students' story sharing, we observed that teachers (community) rephrased key details in the stories in a more general way or identified other stories to help mediate the process of students identifying connections. For example, in this instance, the teacher shifted the initial focus from the mother's Irish family roots, which did not lead to anyone claiming a connection, to the student's father, who is from San Francisco, and asked if anyone connected to California, which inspired many students to speak aloud about their connections in various ways. While creating a physical yarn network allowed students to get to know one another better, they also complained that many of them were unable to connect due to the time constraints and the activity rules that only one new student receives the yarn after each prompt.

To help students see further connections amongst themselves and appreciate the value of computerized network visualizations over physical constructions, one researcher created a digital replica of the yarn network using Net.Create to model students as individual nodes that were connected to other nodes of classmates, significant people, and objects through edges of three categories (like/interested in, connected, important to) (Figure 2 Left). This digital yarn network was used as a starting point for the day 2 activity, in which students worked in pairs (the division of labor) to add more content to the network. Each dyad created new nodes and edges that they felt described their individual interests. While they were asked to enter their individual interests, they worked in pairs so that they could discuss the process, and our intention was that the completed network (Figure 2 Right) represents the class as a whole (rule & division of labor).

Students' comments during the post-activity debrief indicated they had begun to pay attention to the content of the nodes rather than just stating that they knew more about each other. Upon being asked, "What did you learn about your classmates?", many students looked back at the network before responding. They then responded with content that was in the nodes, such as cats (Figure 1 Right), the name of the town, and the state where they lived. The fact that students oriented towards the network visualization and then focused on the specific nodes and edges indicates that they were relying upon the visualization to mediate their response in ways that the yarn network could not, potentially supporting early appreciation for the power of network visualization tools.

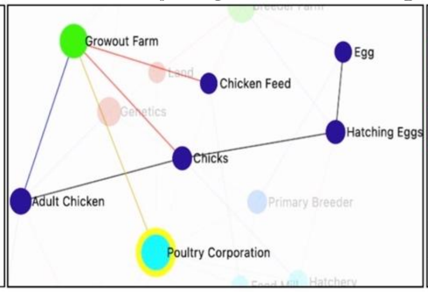
Case2: Understanding the importance of degrees (edge counts)

The activity for day 4 features a pre-built network modeling vertical integration in the poultry industry that was integrated as a part of a teacher-designed project that involved students designing and managing a fictional farm. The teachers had developed this cross-curricular activity because the school is located in a small suburban community adjacent to many rural farm areas, with an active locally sourced food community. Students worked in pairs (the division of labor) and were asked to vote for the top three nodes in the pre-built network that they felt were most crucial for operating a successful chicken farm (rules). There is no "correct" answer to this question, but it was intended to motivate learners to make sense of the network in order to vote. Information contained in the network visualization, including the characterized categorization (indicated by different colors), different numbers of edges, and nodes' sizes, was intended to mediate students' noticing and interpretation.

Figure 3

Left: A subset of the nodes that students attended to. Right: A re-creation of the information in the table view, which showed students' votes juxtaposed with the degrees of centrality (connections).

Left is a subset of the nodes, highlighting the ones students discussed.



Node	Degrees	Votes
Poultry Corp.	11	2
Breeder Farm	8	3
Growout Farm	8	2
Genetics	6	1
Chicks	4	4
Adult Chicken	5	4
Chicken Feed	3	4

Right is a table indicating con nections and votes that students had (re-sorted by votes).

Students initially voted for chicken feed (degree=3; vote=4) and chicks (degree=4, vote=4) as the top two important elements in the network. Students' explanations indicated that their awareness of individual node's content and out-of-school knowledge/experiences mediated their interpretations rather than network features, "I voted for chicks because they are cute, and they are chickens. You need to have chickens to have chicken farms" and "you can feed chicken pretty much anything, … like you can feed chicken chickens." However, when asked whether connections of the network influenced their voting, one student mentioned the importance of connections, "I feel like if the circle node has more connections, then you can tell it is very important." They explained the importance of these connections by stating that "all of (the) things connected to [the node], probably make it happen." This suggests that they recognized the value of degrees of centrality but were not yet aware of how to articulate these ideas. Researchers also asked the two students who voted for the most connected node, poultry corporation (degree=11), why they had selected it. Unfortunately, the students were not able to articulate a reason for this choice.

The next round of exploration prompted students explicitly to consider if the number and types of connections revealed something crucial to a successful farm operation, "let's take two mins to go back to the network and explore this. Tinker with what has a lot of connections and not a lot, and see if you think it matters. … So, you look at and see, do the number of connections or types of connections help you understand." During the discussion, H claimed that the network did not visualize the statement "everything comes from the egg." However, when asked how to redesign the network to emphasize the connection, her response indicated the connection string of egg-hatching egg-chicks (tool, Figure3 left) may be valuable to her recognizing the developmental process starts from eggs, "eggs went to hatching eggs which went to chicks, so I thought, which went to, so, which was very important, so I was thinking about now, egg is where the chicken is born from." We read H's responses as showing that network connections made some relationships more salient to them, although they may still struggle to articulate the significance of connections in the network fully.

Figure 4

Each node's brief introduction

Graph | Nodes Table | Edges Table | More...   brief introduction to each node   < FILTER

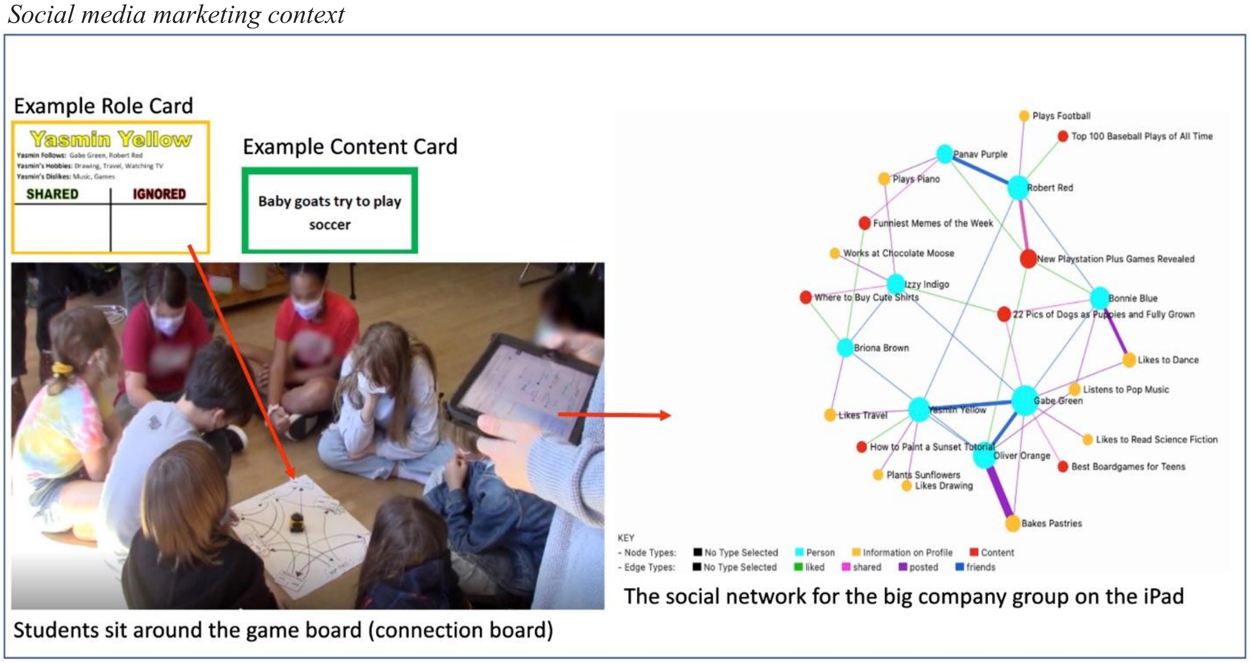
	Degrees ▲	Label	Type	Votes	Notes
View	11	Poultry Corporation	Corporate Owned Facility	2	Major poultry corporations (like Tyson)
View	8	Breeder Farm	Contracted Facility	3	Hatches eggs and sorts the chicks
View	8	Growout Farm	Contracted Facility	2	Takes chicks and raises them to adulthood
View	6	Genetics	Issue	1	Modern chickens have many specialized genetic traits that make them much better as livestock. However, some of these have unintended side effects for the chicken's health.
View	6	Transportation Company	Corporate Affiliate	0	Ships products between different facilities
View	5	Adult Chicken	Product	4	Broiler chickens (special chickens bred to make meat) reach adult weight in just 6 weeks,

Students' tendency to focus on familiar individual data points is also evident in their small group conversations. In one group, despite the teacher's efforts to re-mediate students' attention toward nodes' connection numbers by navigating students in that group to identify nodes with the most and the second most connections, they remained focused on a node, adult chicken, "yes, but me and M voted adult chicken three times because you need adult chicken to get chicks." In the whole-class discussion, we observed the teacher's continued mediation of orienting students' attention to the nodes' connection numbers by rationalizing their votes, "when we see what the second most important thing, we found this growout farm. and this connected directly to you H because this growout farm takes chicks and raises them to adulthood." The teacher's explanation of the growout farm was based on a brief introduction (Figure 4) of that node that we incorporated into the Net.Create design (tool). Thus, the interface further mediated the teachers' and students' exploration of the chicken industry. The teacher also aimed (a division of labor) to help re-orient the students' attention toward the number of connections and node details as the students explored the network. While not all of the students shifted their activity, they did all have the opportunity to participate in the resulting whole-class discussions that built on these interactions, giving them a chance to notice the same connections their peers did, which may have helped in later activities.

Case3: Make inferences based on a combination of connections numbers and edges types

Case 3 involves students playing a board game designed by the research team in which they were divided into two groups (a division of labor), with one representing big companies (e.g., TikTok) and another representing fictional social media users. A Net.Create social network (tool) was made available to the big company group allowing them to gain information about the social media users' profiles, the content they shared/liked, and people whom they are friends with (Figure 5). Students in this group were given a series of content cards that represented social media memes (e.g., sports videos, or cute puppy videos) and were tasked with leveraging network information to identify the best user who would see a content card first and then disseminate the content through the network to more users (a division of labor). For example, students might give the "cat video" card to a user whose media personality indicates loving cats. The media users group has a connection board (a tool) (Figure 5) with information about who follows whom on social media so as to determine how to distribute the content card once they receive it (a division of labor). In addition, each user receives a role card (a tool, Figure 5) summarizing their likes and dislikes as a reference to choose whether or not to share the content card chosen by the big company group (rule). As part of this activity *rule*, the social network visualizes users' partial interests. Therefore, to develop an effective marketing tactic of distributing a content card to a bigger audience (object), it becomes essential for the big company group to use the social network to infer influencers and their interests.

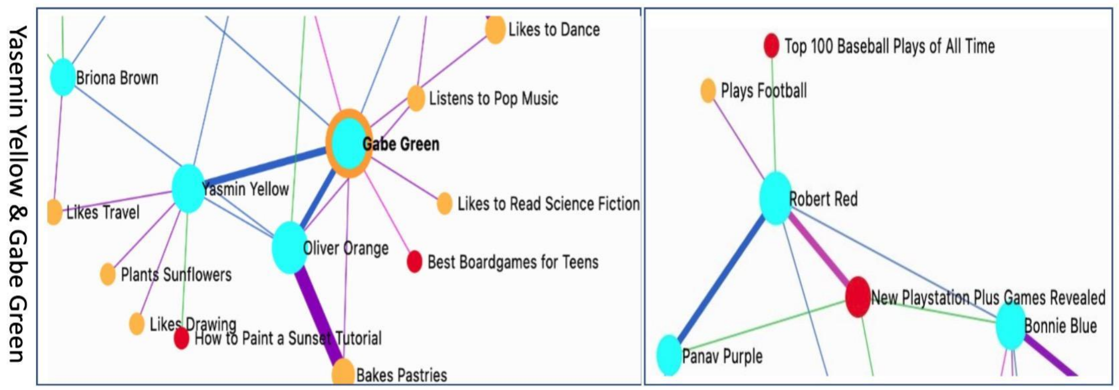
Figure 5
Social media marketing context



The initial conversation on marketing strategy demonstrated that students' network visualization reasoning is mediated by their emergent understanding of how networks work. O shared her marketing strategy of passing a content card to those with the most connections, and her game-playing aligns with the strategy. Her first marketing attempt was to choose Gabe Green (Figure 6 Left), who has the greatest connections (degree=11), to receive the content card "Best Sports Bloopers of the Week." However, this content card was ignored because of Green's distaste for sports. O's second trial chose Yasmin Yellow (Figure 6 Left), who has the third-highest number of connections (degree = 8); however, the chosen content card concerning music (Playlist: Music to paint to!) is what Yasmin Yellow finds objectionable. Thus, neither content card spread to the second player since the card content did not match the person's interests and was disregarded. Here, we interpret O's strategy as mediated by the idea of using the connection number of a node to assess its significance, which may be learned from the chicken industry network; however, this strategy failed to completely utilize the social network as a mediational means to make inferences, as O only attends to connection numbers of nodes and ignores edge types and connected nodes. This was a great opportunity to help students re-orient toward the specific node and edge content.

Figure 6

Yasemin Yellow & Gabe Green (Left) Robert Red (Right) connections



The next player was H, whose marketing strategy was more successful as the content card she chose spread to many of the other peers. In the final discussion, O summed up H's marketing strategy as choosing the first person "based on what was being liked, instead of giving it (content card) to somebody randomly." Here, how H played the game (a division of labor) functions as a mediational means for O to identify the best marketing strategy. We reviewed H's gameplay to see if this was indeed her strategy. H role-played the big company and picked a content card of "Highlights of local sports games." She talked out loud about the card content to the teacher (community) who participated in this group as a social media user. Then, the teacher (community) began to look at the role cards of the users sitting next to him to determine who likes/dislikes sports. However, this violates the game *rule*, in which the company group is supposed to rely only on the social network. A researcher halted this infraction by reminding them of the rule, which prompted H to turn to the social network on the iPad. While zooming in on the social network, H murmured, "Who likes, ok, Robert really likes Sports." She continued to zoom in and out of the social network silently before finally handing Robert Red the content card. It was unclear what other factors H was considering before choosing Robert Red; however, H's marketing strategy turned out very effective. This is because Robert Red is the third most connected node (degree = 8) and enjoys sports, as indicated by his sharing of sports content (Figure 6 Right). Although we do not have a full picture of H's reasoning, her pick of Robert Red and the accompanying murmuring indicate her attention to what was being connected to the Red's node (e.g., interests). H's successful marketing plan of identifying the right person to promote a content card matching the person's interest is mediated by the teacher's guidance in getting her to find whose interests match the content card within the network visualization (tool). Thus, it appears that H's successful marketing strategy mediated O to notice the importance of what and how nodes are connected in addition to the connection numbers (a division of labor).

Discussion

This study demonstrated that elementary students are able to use network visualizations productively to make sense of a wide range of topics related to both their classroom pursuits and data literacy. We reported how different mediators present across the three activities supported students' data reasoning in the network visualization. Case one explicates different mediations of the physical network and the virtual network in supporting students' exploration and comprehension of connections. Case two showed explicit conversations about connections and Net.Create's built-in features mediated a discussion of a more interconnected view. Case three illustrates that students' understanding built on their emerging understanding of networks and different roles-taking attuned them to connection numbers and information flows in the network. Attending to students' participation in four network visualization activities provides insights for activity designers and classroom teachers into how mediation in activities and discussion was necessary to support students in exploring network visualizations as aggregate representations as opposed to focusing solely on specific nodes they are familiar with. While not all students appeared to display a nuanced articulation of network visualizations, many developed an appreciation for the affordances of network visualizations for exploring patterns in data. Like with other data representations and previous research (e.g., Ben-Zvi & Arcavi, 2001), familiarity with individual ideas continued to distract some students from aggregate patterns, but we view the results as promising given that many students did begin to exhibit emergent attention to those aggregate patterns. In addition to developing students' data literacy skills, this project highlighted the potential of network visualizations as a vehicle for leveraging locally relevant content (e.g., students' interests and the classroom focus on the poultry industry) and incorporating physical activities (e.g., yarn activity and board game) to help students make some of the relationship relevant to them. In the future, we will further explore how we can re-mediate learners' activities to help even more students attend to these network features and explore how network visualizations might support other dimensions of data literacy.

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