

The Role of Visual Representations Within the Scientific Practice of Explanation

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Abstract: Two Grade 5/6 classes (n=47) participated in an 8-week biology unit where they investigated WallCology, a digital ecosystem. During a series of oral presentations, students presented findings from their digital experiments. Our goal is to understand the role of the visual representations (e.g., digital screens, graphs) that students referenced during these presentations. We use the Claim Evidence Reasoning framework to establish the suitability of the presentation task for scientific explanations and for evaluating students' explanations. We show that student groups were proficient in their scientific explanations and effectively used a variety of representation types across all three components of their explanations. We conclude that visual representations did not just influence scientific discourse, but were part of it.

Introduction

A fundamental aim of science is to explain the world around us, in order to make sense of how and why various phenomena occur (Berland & Reiser, 2009). Scientists use a variety of representations (e.g., diagrams, equations, notations) to communicate what is currently known about phenomena, even whilst they are still working on a problem (Prain & Tytler, 2013). However, in typical science classrooms, learners are rarely afforded the opportunity to engage with visual representations in ways that align with scientific practice (Ainsworth, Prain, & Tytler, 2011). Instead, a common practice is to ask learners to construct representations *of something*, rather than to produce a representation *for something* (i.e., serving a concrete purpose, such as communicating to peers) (Greeno & Hall, 1997). If learners are to become more than passive consumers of science, educators need to envision scenarios where learners have the opportunity to invent, modify and discuss scientific representations (Danish & Enyedy, 2007). In this paper, we present a study where students are presented with the challenge of making sense of unfamiliar scientific phenomena and are offered the opportunity of “practicing representations” (Greeno & Hall, 1997) as they engage in the scientific practice of explanation with their peers.

Theoretical foundations

A scientific explanation responds to a question, using data analysis and interpretation of scientific principles. The Claim Evidence Reasoning (CER) framework (McNeill & Krajcik, 2011) is designed to provide students with guidance on how to structure scientific explanations that are part of their scientific writing, discussions, and oral presentations. This instructional model includes three components (claim, evidence, and reasoning) and asks learners to create a coherent explanation by linking all three components together, with evidence providing support for a claim and reasoning linking evidence to the claim. To date, research that uses the CER framework has not focused on the role of visual representations within the scientific practice of explanation. To that end, this paper offers a new dimension that can contribute to this body of work.

WallCology narrative

WallCology is a digital simulation that is part of the Embedded Phenomena framework (Moher, Uphoff, Bhatt, López Silva, & Malcolm, 2008). WallCology consists of fictional animated species that interact with each other and the environmental features of their ecosystem. Students investigate ecological concepts, such as how species interact with each other (e.g., producer consumer relationships) and the effect of environmental stressors on population levels.

In the first phase of the unit, students are introduced to the environment when their teacher asks them to imagine that there are four distinct ecosystems that exist behind each of their classroom walls. They are told the only way to view them is through specialized “wallsopes” (i.e., digital monitors). Students are tasked with observing the ecosystems and asked to pay close attention to the behaviors and interactions of digital species. Each ecosystem contains its own unique configuration of abiotic characteristics including temperature, available pipe, and available brick, as well as a unique subset of the 11 WallCology species. These factors combine to create a complex inquiry space for students to explore. The students work together as a scientific community to understand how each species interacts with its environment and to discover the food web relationships among

the species. In the second phase of the unit, a major perturbation (e.g., habitat destruction, climate change) impacts each ecosystem, causing dramatic changes to population levels within the ecosystems. Working in one of four table groups, students are then challenged to uncover the chain of events (starting from the initial perturbation) that led to the current state of the ecosystem. In the final phase of the unit (the investigations phase), student groups are given the opportunity to adjust the population levels of species within each ecosystem (by increasing or decreasing them) and to introduce new species into the ecosystem. After each investigation cycle (ecosystem manipulation), student groups present the results of each “investigation” to their peers in the form of an oral presentation. The role of visual representations within the scientific practice of explanation as demonstrated through these presentations is the focus of this study.

Research questions

In this study, we explore how students engaged in scientific explanations as part of the presentations that they made within the investigation phase of the WallCology unit, with a focus on the types of visual representations that they elicited as evidence for their claims. The following research questions guided our analysis.

1. How does the WallCology curriculum and learning environment create opportunities for students to engage in the scientific practice of explanation?
2. What role do visual representations play within each component of students’ scientific explanations (e.g., claim, evidence, and reasoning)?

Methodology

Participants

This study was conducted at a university laboratory school in Ontario, Canada. The school has a long history of promoting inquiry-based approaches to learning and instruction, including knowledge building and learner-centered pedagogies. The student body consisted of learners from varied cultural and socio-economic backgrounds. Two Grade 5/6 classes participated (n=47), along with their teachers, Brad and Mark (pseudonyms). Both Brad and Mark had experience in facilitating collaborative forms of learning within their classrooms, with ten and five years of teaching experience respectively.

Learning environment and curriculum materials

Two research groups from the University of Toronto and the University of Illinois at Chicago and classroom teachers from our partner schools participated in a co-design process (Roschelle, Penuel, & Sheckman, 2007) to design and develop the learning environment and technology-enhanced learning materials. Co-design processes can foster a sense of trust among design team members and can ensure that innovations are a good fit for a particular classroom context.

Technology designs

The co-design team, including teachers, researchers, software developers and graphic artists, worked together to create a suite of web-based tools to support idea and knowledge exchange among students as they progressed through the WallCology narrative. Included within these tools was a brainstorm space, where students could share newly emerging ideas with peers, an observation space, where students could exchange structured notes (including visual media) and pairwise observations about producer-consumer relationships, a population graph tool, where students could specify species and environmental factors (e.g., temperature) to compare, and an investigation space, for student groups to propose a population change to one or more species in an ecosystem, predict how all other species will be affected by the change, justify predictions, and record the results of the investigation, including an explanation for the reported results.

In this study, we focus on students’ use of the *investigation space*, and consider how they used the presentation screens within that tool to spotlight the important elements of their investigations. The investigation space consisted of several screens that allowed students to proceed stepwise through each stage of their investigation to (1) describe the current state of the ecosystem (i.e., health of the ecosystem as evidenced by population levels), (2) write an investigation plan whose goal is to improve the overall health of the ecosystem, (3) make a prediction concerning the outcome of an investigation (i.e., manipulation to the population of one or more species), and (4) report the results of their investigation. After contributing descriptions, plans, predictions, and reports for all stages of their investigation, students could display a condensed view of their investigations using the tools *present screens*: plan, predict, and results. We designed these three views to allow students to easily show their peers an overview of their investigation by reducing the number of screens that they would

have to display during their presentations. Using these present screens, students could tap on attached media to enlarge them. Figure 1 shows a student group displaying an investigation present screen on the classroom SMART Board during one of their investigation presentations.

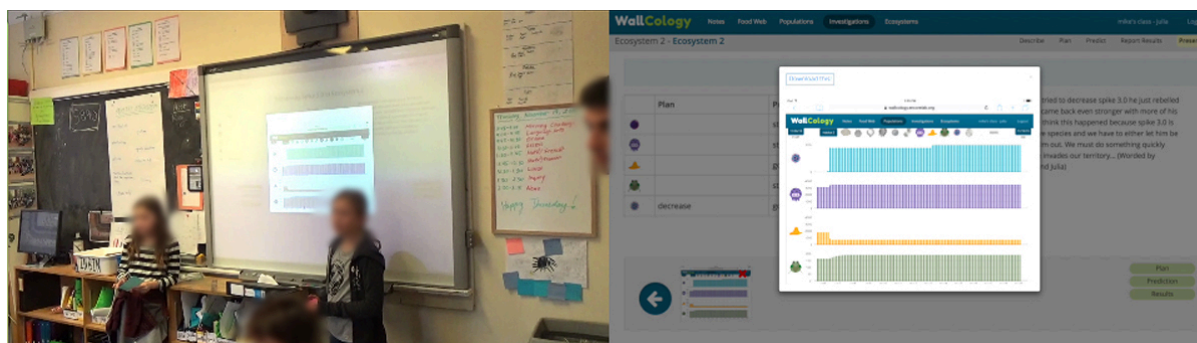


Figure 1. Student group enlarges media (a graph) during one of their investigation presentations.

Activity designs

An important aspect of our activity designs was requiring students to engage in scientific explanations, particularly within the investigations phase of the unit. The classroom teachers introduced the investigations phase by asking students to consider the question: *What makes an ecosystem healthy?* Through whole class discussion, both classes elaborated on this concept and identified many features that would be indicators of the overall health of an ecosystem (e.g., balance of prey and predators, variety of species, able to support life). Teachers captured the important ideas from these discussions in concept maps that remained on display for the investigation phase.

Brad and Mark explained that table groups would have the opportunity to make adjustments to the digital ecosystem that they were responsible for using one of three mechanisms: introducing one or more new species, increasing a species that was already present in the ecosystem, or decreasing an existing species. The teachers reminded their students that in order to be successful in improving the health of their ecosystems, they would have to take into account the underlying cause of the changes in the ecosystems. For example, in Ecosystem 3, when an invasive predator entered the ecosystem, the indigenous predator was eliminated because the new predator had a significant advantage; it was a location generalist, whereas the indigenous predator was a location specialist (i.e., only existed in the brick habitat). The invasive predator had access to food sources that the indigenous predator did not. Since each ecosystem was impacted by a different perturbation, each table group needed to address a unique set of issues. However, because the interactions among species and the ways that species interacted with the abiotic features of their habitat were consistent across ecosystems, student groups needed a forum to share their scientific explanations with the entire knowledge community. The format for this knowledge exchange was the *investigation presentations*, where students used the present screens that are described above as a shared referent during their scientific explanations.

Analysis and findings

Research question #1

In the first phase of our analysis, we evaluated the WallCology learning task (i.e., investigation presentations) to establish that CER was “a good fit” to be used as a framework to evaluate students’ scientific explanations. We mapped the WallCology learning task to three categories outlined by McNeill and Krajcik (2011): (1) opportunities in the curriculum that are appropriate for CER, (2) the complexity of the learning task, and (3) classroom supports. To perform this mapping, we used a variety of data sources including provincial curriculum documents, field notes, photographs, and video recordings.

Opportunities in the curriculum

To establish that WallCology presented a sufficient curricular *opportunity*, we looked at “learning performances” (i.e., a specification of what the students should be able to do, given both the content standard and scientific inquiry standard that is being targeted within a given activity) McNeill and Krajcik (2011). For this analysis, we were interested in examining the learning performances that related to the investigation presentation task. The co-design team consulted curriculum guidelines outlined by the Ontario Ministry of Education (2007) during the design phase and sought to map these curriculum goals to our activity designs. The

sixth grade “Understanding Life Systems: Biodiversity” unit outlines both content standards (i.e., expectations of student performance) and scientific inquiry standards (e.g., experimentation skills). According to McNeill and Krajcik (2011), a learning performance is defined as a product of content standards and scientific inquiry standards. Table 1 provides an overview of the learning performances that were part of the WallCology investigation presentation task.

Table 1: Overview of the learning performances that were part of the WallCology investigation task

| Ontario curriculum expectations | Scientific inquiry/experimentation skills | WallCology learning performance |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 3.2. Demonstrate an understanding of biodiversity as the variety of life on earth, including variety within each species of plant and animal, among species of plants and animals in communities, and the physical landscapes that support them (p. 114). | Initiating and planning Students make predictions, based on prior knowledge from explorations and investigations about the results of an investigation (p. 13). | Students use their understanding of the WallCology ecosystems, including environmental characteristics and the species that inhabit each one, to plan, make predictions , and report on the results of each investigation. |
| 3.7 Explain how invasive species reduce biodiversity in local environments (p. 114). | Analyzing and interpreting data Students identify patterns in the data, suggest explanations for discrepancies, and summarize the data. Students draw conclusions on the basis of data gathered (p. 14). | Students explain how an invasive species can reduce the biodiversity within their WallCology ecosystem, drawing on available data, such as their own observations and population graphs. |
| 3.3 Describe ways in which biodiversity within species is important for maintaining the resilience of these species (p. 114). 3.4 Describe ways in which biodiversity within and among communities is important for maintaining the resilience of these communities (p. 114). | Communicating Student present steps in and results of an experimental procedure using numeric, symbolic, graphical, and/or linguistic methods (p. 14) to answer the question investigated (p. 16). | In the form of an oral presentation, students state a claim about the overall health of their ecosystem. They present their investigation plans/predictions/and reports to their peers, answering the question “How can we/did we improve the overall health of our ecosystem?” |

As shown in Table 1, the WallCology learning performances associated with the investigation presentation task required that students engage in meaningful scientific explanation, combining curriculum expectations with scientific inquiry/experimentation skills. Students had to state a *claim* about how the health of their ecosystem will be improved through their manipulation, provide *evidence* in the form of known food web relationships and changes in population sizes of other species, and give *reasoning* about how changing the population of one species impacts multiple species in the food web, including both direct and indirect relationships.

Complexity of the learning task

Complexity of the learning task can be described in terms of two aspects: (1) openness of question, (2) type of data, and (3) amount of data. The WallCology learning environment is on the more complex end of the spectrum in all three of these areas. Table 2 provides an overview of these three areas to demonstrate that students were working in a complex inquiry space. For example, students provided explanations in response to open-ended and semi-structured questions, rather than highly structured questions. Also, students used multiple forms of data, including quantitative, qualitative, and even contradictory data. The inquiry space was large and highly complex, with student groups having the ability to manipulate multiple species in one investigation and to perform multiple consecutive and accumulative investigations.

Table 2: Three aspects that describe the complexity of the learning task

| Openness of question | Type of data | Amount of data |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Students constructed explanations in response to open-ended questions : <ul style="list-style-type: none"> How can we improve the health of our ecosystem? | Students used multiple forms of data to construct their explanations. Qualitative data: <ul style="list-style-type: none"> Students made observations about | <ul style="list-style-type: none"> Students could manipulate up to 11 species at one time. Students performed multiple |

| | | |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <ul style="list-style-type: none"> How can the factors under our control be manipulated to improve the health of our ecosystem? <p>Students also made claims in response to semi-structured questions:</p> <ul style="list-style-type: none"> Is our ecosystem more or less healthy than it was prior to our last manipulation? How has the introduction of an invasive species (the increase in temperature or habitat loss) contributed to a reduction in the health of our ecosystem? | <p>the populations of species within their ecosystem and about the state of the habitats within their ecosystem.</p> <p>Quantitative data:</p> <ul style="list-style-type: none"> Students constructed population graphs using the WallCology graph tool. Students constructed population graphs using the graph tool. Students considered seemingly contradictory data. | <p>consecutive and accumulative investigations.</p> <ul style="list-style-type: none"> Students attended to the investigations and ecosystems of other groups, not just their own. |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

Classroom supports

McNeill and Krajcik (2011) recommend that the components of the CER framework be displayed in the classroom as a memory aid for students as they provide written or oral explanations. Such charts could contain varying degrees of detail, from categorical titles (CER), to titles with descriptions and/or examples. In the classrooms we studied, there were no representations that referenced CER on display. However, the representations that captured the healthy ecosystem discussion (i.e., concept maps) remained on display throughout the investigation phase. These underlying concepts provided guidance for student groups as they constructed claims regarding the health or future health (i.e., after a manipulation) of their ecosystem.

According to McNeill and Krajcik (2011), curricular scaffolds are “sentence starters, sub-questions, graphic organizers, or prompts that help break down the task and provide students with hints on how to successfully complete the scientific explanation task” (p. 60). Our technology designs included CER specific language within the investigation phase prompts. McNeill and Krajcik (2011) also distinguish between general and content-specific scaffolds. General scaffolds provide support for scientific explanation but could be used with any content. Content-specific scaffolds provide support that is specific to the content area and to the task. The prompts that were provided to students in the investigation space were content-specific because they related directly to the tasks of planning, predicting, and reporting on a WallCology investigation. Table 3 provides a mapping of CER components to curricular scaffolds.

Table 3: CER components mapped to the WallCology curricular scaffolds

| CER component | WallCology curricular scaffolds |
|---------------|----------------------------------------------------------------------------------------------------------------------------|
| Claim | What is your goal? What are you hoping to accomplish? |
| | What were the results of this investigation? |
| Evidence | You can add evidence to support your prediction (e.g., food web) |
| | For each species, choose whether the species went up or down. |
| Reasoning | Give your reasoning |
| | Justify your predictions. Why will some species go up or down? How do these changes affect other species in the ecosystem? |

Research question #2

The second phase of our analysis concerns the role of visual representations within the investigation presentation task. We analyzed all investigation presentations given by student groups in both Brad and Mark’s classes (n=32). We analyzed the content of student groups’ scientific explanations using a customized rubric, drawing on McNeill and Krajcik (2011). Table 4 presents a succinct version of this rubric. We cross-referenced each CER component with the type of visual representation(s) that students referenced during their presentations. We chose to include multiple forms of visual representations including system-generated resources (i.e., investigation present screens) and student-generated representations (e.g., population graphs, photographs). We also considered other knowledge resources that students referenced, including when they cited the “wallsopes” themselves. We used StudioCode to analyze the investigation presentation videos and created segments according to the claim, evidence, and reasoning portions of student groups’ explanations. We coded segments with labels to describe representation types (learning environment, investigation screens, graphs, other representations, and none) and to describe the CER level that we assigned to each segment, using the customized rubric.

Table 4: Succinct view of customized CER Rubric

| CER Component | Level | | |
|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| | 0 | 1 | 2 |
| Claim – A conclusion that answers the original question: How can we make our ecosystem healthier? | Does not make a claim | Makes an accurate/reasonable but incomplete claim (i.e., does not relate to healthy ecosystem concepts and/or underlying cause of change to ecosystem). | Makes an accurate/reasonable and complete claim (e.g., relates to healthy ecosystem concepts and/or addresses underlying cause of change to ecosystem). |
| Evidence – Scientific data that supports the claim. The data needs to be appropriate and sufficient to support the claim. | Does not provide any evidence or provides only inappropriate evidence (i.e., inaccurate) | Provides appropriate evidence (e.g., based on observations, known facts about the ecosystem such as food web relationships, or analysis of graphs), but is insufficient to support claim. | Provides appropriate and sufficient evidence (e.g., based on observations, known facts about the ecosystem such as food web relationships, or analysis of graphs to support claim. |
| Reasoning – A justification that links the claim and evidence. It shows why the data counts as evidence by using appropriate and sufficient scientific principles. | Does not provide reasoning or provides reasoning that does not link evidence to the claim. | Provides reasoning that links the claim and evidence, but does not include appropriate and sufficient scientific principles (e.g., healthy ecosystem concepts or underlying cause of change to the ecosystem). | Provides reasoning that links evidence to claim. Includes appropriate and sufficient scientific principles (e.g., healthy ecosystem concepts, referencing underlying cause of change to the ecosystem). |

Using the rubric shown in Table 4, we evaluated each component of student groups' explanations, giving it a score of 0, 1, or 2. There were a total of 19 claims made in Brad's class and 18 claims made in Mark's class. In Figure 2, we present the results of our CER analysis. Student groups in both classes achieved more level 2s with their reasoning than with their evidence. In Brad's class, they achieved more level 2s with their evidence than in making claims; in Mark's class, this result was reversed.

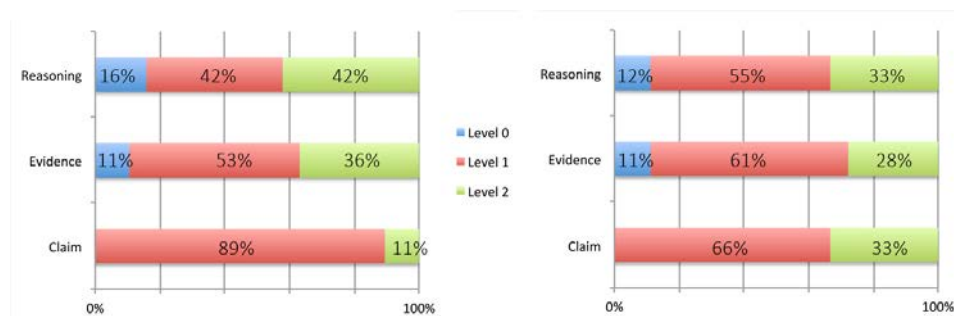


Figure 2. CER levels of student groups' in Brad's class (left) and Mark's class (right).

Next we examined the percentage of instances when student groups made reference to one or more visual representations during each CER component. Student groups in both classes directly referenced visual representations most frequently during the *evidence* component of their explanation—approximately 80% of the time. However, student groups also referenced visual representations with high frequency during both the *claim* and *reasoning* components of their explanation, with some variation across classes (see Figure 3). To see if there was any possible connection between whether or not a student group utilized a visual representation and the level they scored in each CER component of their explanation, we calculated co-efficient values for these variables. In all instances, there were no positive correlations. Similarly, when we also looked for a connection between number of visual representations utilized and CER levels, we found no positive correlations.

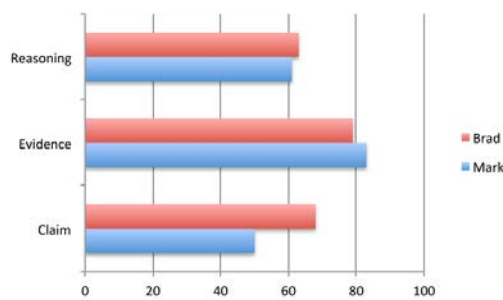


Figure 3. Percentage of time student groups made reference to a visual representation during CER components.

Finally, we examined the type of representation (e.g., investigation screens) that student groups referenced during each CER component (see Figure 4). While we were not able to show that there was any strong correlation between reference to a visual representation or a specific type of visual representation and higher CER level scores, our analysis shows that student groups successfully used the investigation screens to support all three CER components of their explanations. Students used a variety of other representations to support their explanations, sometimes using more than one type within a single CER component, and most often during the evidence component of their explanations.

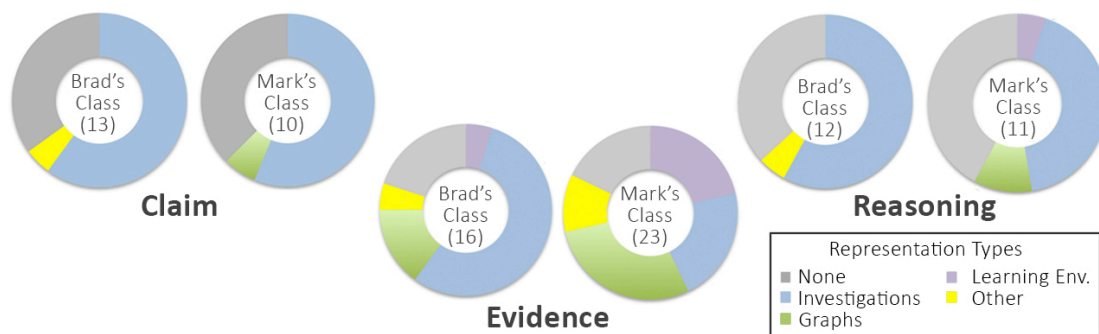


Figure 4. Breakdown of representation types referenced during each CER component for Brad and Mark's classes, with totals shown in brackets.

Discussion

By mapping the WallCology curriculum designs to the three features outlined by McNeill and Krajcik (2011), we were able to portray a complex inquiry space that created space for students to engage in the scientific practice of explanation. An activity structure that allows students to persuade an audience that is unfamiliar with their data and work is not typical in science classrooms (Berland & Reiser, 2009). The WallCology curriculum design created opportunities for learners to construct complex scientific understandings through socially connected processes (Engle & Conant, 2002; Gray & Szalay, 2007). In the presentation task, student groups were only moderately familiar with the specifics of other ecosystem investigations, making them “unfamiliar readers” of each other’s work (Berland & Reiser, 2009). The implicit goal, therefore, of the student groups’ presentations was that of *persuasion*—to provide evidence (connected by reasoning) to support a claim that they had made about their ecosystem. By carefully evaluating another groups’ explanations, student groups could determine whether or not to incorporate new approaches and evidence into their own future investigations.

Greeno and Hall (1997) speak about “practicing representations” as part of social practice. It involves “learning to participate in the complex practices of communication and reasoning in which the representations are used” (p. 361). During the investigation presentations, student groups used various forms of visual representations as a communication tool. They were able to demonstrate their ability to understand and interpret traditional forms (e.g., graphs, food web relationship diagrams), but they also put these representations to use, and used them as a device to strengthen their explanations. Greeno and Hall (1997) distinguish between representations that are *of something* and representations that are *for something*. During the investigation presentations, student groups took representations that were *of something* (e.g., simulation screens that were

visible in the classroom) and retooled them into representations that were *for something*. In addition to “practicing representations” as a form of social practice, student groups used various representation types as a form of scientific practice. Although the investigation presentations were a form of culminating task, students groups presented to their peers while they were making new discoveries and refining their understanding. In this sense, students were engaging in work with representations in a manner that is similar to the way scientists use representations. Student groups coordinated a variety of representation types and used them with competence and fluency and to support their knowledge claims. Our study portrays a scenario in which visual representations played a vital role. They did not just influence or support scientific discourse; rather, they became woven into the fabric of the discourse.

Limitations

During design discussions, the teachers on the co-design team indicated that they would like to include the language of “claim, evidence, and reasoning” in our prompts. The co-design team included scaffolds that asked students to stake a claim (by responding to a driving question) and to use the language of “evidence” and “claim.” However, the students themselves were not explicitly guided to use the framework during their presentations, nor did the teachers explicitly model the approach. Nevertheless, the classroom culture had long established knowledge building practices that provided learners with the necessary background to engage in the scientific discourse of explanation.

References

- Ainsworth, S., Prain, V., & Tytler, R. (2011). Drawing to learn in science. *Science*, 333(6046), 1096-7.
- Berland, L. K., & Reiser, B. J. (2009). Making sense of argumentation and explanation. *Science Education*, 93(1), 26-55.
- Brown, A. L., & Campione, J. C. (1996). Psychological theory and design of innovative learning environments: On procedures, principles, and systems. In L. Schauble and R. Glaser (Eds.), *Innovations in learning: New environments for education*, (pp. 289-325). Mahwah, NJ: Lawrence Erlbaum Associates.
- Danish, J. A., & Enyedy, N. (2007). Negotiated representational mediators: How young children decide what to include in their science representations. *Science Education*, 91(1), 1-35.
- Engle, R. A., & Conant, F. R. (2002). Guiding principles for fostering productive disciplinary engagement: Explaining an emergent argument in a community of learners classroom. *Cognition and Instruction*, 20(4), 399-483.
- Gray, J., & Szalay, A. (2007). *eScience - A transformed scientific method* (PowerPoint slides). Retrieved from http://research.microsoft.com/en-us/um/people/gray/talks/NRC-CSTB_eScience.ppt.
- McNeill, K. L., & Krajcik, J. S. (2011). *Supporting Grade 5-8 Students in Constructing Explanations in Science: The Claim, Evidence, and Reasoning Framework for Talk and Writing*. Boston, MA: Pearson.
- Moher, T., Uphoff, B., Bhatt, D., López Silva, B., and Malcolm, P. (2008). WallCology: designing interaction affordances for learner engagement in authentic science inquiry. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI)*. (pp. 163-172). ACM.
- Ontario Ministry of Education. (2007). *The Ontario Curriculum Grades 1-8: Science and Technology*. Retrieved from <http://www.edu.gov.on.ca/eng/curriculum/elementary/scientec18currb.pdf>
- Penuel, W.R., Roschelle, J., & Shechtman, N. (2007). Designing formative assessment software with teachers: An analysis of the co-design process. *Research and Practice in Technology Enhanced Learning*, 2(1), 51-74.
- Prain, V. & Tytler, R. (2013). Representing and learning in science. In R. Tytler, V. Prain, P. Hubber & B. Waldrup (Eds). *Constructing representations to learn in science*. Sense Publishers: Amsterdam, p 1-14.
- Studiocode Group. (n.d.). Retrieved October 29, 2016, from <http://www.studiocodegroup.com/>

Acknowledgments

We heartily thank the teachers who partnered with us to design and implement the curriculum. We also thank their students, who enthusiastically engaged in this curriculum. The authors are grateful for the substantial support that was provided by many members of the Encore Lab, notably, Renato Carvalho, Armin Krauss, Colin McCann, and Meagan O'Hara. The material presented is based on work supported by the U.S. National Science Foundation under grants IIS-1065275 and DRL-1020027, as well as the Canadian Social Sciences and Humanities Research Council under grant 410-2011-0474.