Exploring A Digital Tool for Exchanging Ideas During Science Inquiry

Camillia Matuk and Marcia C. Linn, University of California, Berkeley
Email: cmatuk@berkeley.edu, mclinn@berkeley.edu

Abstract: Practicing science increasingly involves knowing how to participate in a networked knowledge community. This includes expressing scientifically informed ideas, sharing ideas with peers, and evaluating multiple sources of information. Effective instruction builds on students' prior ideas, enables them to benefit from exchanging ideas with others, and supports them learning from one another. How might technology support these exchanges? And how might documenting these exchanges inform teachers' and researchers' improvements to their instruction and design? We describe the Public Idea Manager, a new curriculum-integrated tool that supports students exchanging ideas during web-based science inquiry. Our exploratory analyses show relationships between the diversity and sources of students' ideas and the quality of their explanations. We discuss implications for formative assessment, and for the role of technology in supporting students to engage more meaningfully with information and with each other.

Supporting the Exchange of Ideas During Science Inquiry

One of the most effective ways to support the understanding of science is to build upon learners' prior knowledge. But amid the multiple constraints of the classroom, it can be difficult for teachers to address students' diverse ideas, which are often conflicting and incomplete (diSessa, 2000). Tools that promote collaboration offer numerous advantages for students promoting one another's understanding. They also emphasize participation in authentic scientific communities. The potential for such tools to capture fine-grained information on students' exchanges can moreover help researchers and teachers better understand and support students' inquiry.

In this paper, we describe a curriculum-integrated tool that supports students exchanging ideas throughout the process of constructing scientific explanations. We present classroom findings on how middle school students used the tool during a life sciences unit, and how the sources and diversity of their ideas related to the quality of their explanations. We discuss implications of our findings for inquiry instruction, and next steps in research and design.

Theoretical Background

Explanation is a hallmark of science inquiry, but challenging for students. They have difficulty using evidence to support their claims (Sandoval, 2005), coordinating evidence from multiple sources and with multiple alternative hypotheses (Kuhn et al., 1995; Schauble, 1996), refining arguments in light of new evidence (Chinn & Brewer, 1998), and articulating ideas in writing (McNeill & Krajcik, 2008; Sandoval & Millwood, 2005). Planning activities, such as generating, organizing, and linearizing ideas can help, but students rarely do this (Andriessen et al., 1996). It is therefore not surprising that continuous guidance for developing explanations is useful (Quintana et al., 2004).

Our research and curriculum design is guided by the Knowledge Integration (KI) pattern (Linn & Eylon, 2011). This perspective assumes that learners hold multiple, often contradictory views of any one science topic and that learners deliberately distinguish and make connections between new and existing ideas (diSessa, 2000; Eylon & Linn, 1988; Linn & Hsi, 2000; Slotta et al., 1995). Instruction guided by KI thus emphasizes eliciting students' existing ideas; helping them explore additional; more normative ideas; and guiding them to reflect on distinguishing and sorting out alternatives as they build an integrated understanding.

In other words, the KI pattern would suggest learning benefits in initially diversifying and then converging on ideas as learners reflect upon and refine their understanding. Research on brainstorming across domains finds differential benefits of convergent and divergent thinking during different phases of problem solving (Cropley, 2006). Other research suggests that the kind of information encountered in collaborative knowledge building environments can affect how one revises their ideas. Exposure to incongruous information in Wikipedia, for instance, was more likely to prompt editors to revise their ideas than exposure to congruous information (Moskaliuk, Kimmerle, & Cress, 2012).

Existing collaborative environments offer tools with which learners can build upon one another's ideas (e.g., Scardamalia & Bereiter, 2006). Often, however, middle schools students require more explicit scaffolding to guide their construction of scientific explanations than are available in such environments. Questions also remain over how to make sense of what occurs during the free exchange of ideas. For instance, one might anticipate the exposure to peers' ideas to result in either the diversification or the reinforcement of students'

own ideas. But how do students make decisions over which ideas from their peers to incorporate? And how can technology capture these decisions to inform more effective instruction?

Goals and Research Questions

We designed a tool called the *Public Idea Manager (IM),* which would (1) allow students to access each others' ideas as learning resources when refining their own understanding; and (2) capture students' exchanges of ideas in order to inform teachers and researchers of better ways to support students collaborative learning.

In this initial exploratory study of a larger design-based research program, we wished to know how students would take advantage of the tool. Our specific research questions were (1) how would students use a tool that supports the exchange of ideas among peers? That is, would they freely share ideas, or would they be reluctant to do so? Would they tend to copy ideas from their peers rather than generate their own? When students do copy peers' ideas, would they recognize good quality ideas? And (2) how would the diversity of students' individual repertoires of ideas change as a result of their access to a public idea repository? Moreover, how might the relative diversity of students' ideas, and the source of those ideas (generated by oneself or copied from one's peers), relate to the quality of students' scientific explanations?

Through the design of a tool for exchanging ideas, this research provides opportunities for students to participate in more authentic collaborative science inquiry. It moreover provides researchers and teachers ways to better understand the role of technology in mediating students engaging with each other's ideas, and drawing on their peers to support their explanations.

Methods

Participants and Setting

Participants were 297 students in a middle school in the western United States. Their two teachers had 5 class periods each, and collaborated closely to coordinate lesson plans and grading. One teacher had taught the WISE unit (described below) for more than 8 years, while the other teacher had taught it for 3 years. Students mostly worked as partners on the unit during one 50-minute class period on each of 7 consecutive school days. Two more days before and after this time were spent completing a pre and posttest (described below). Meanwhile, the teachers circulated the classroom to offer guidance on the material or assistance with the technology as needed. A researcher was also present in the room on most days, but mainly sat apart from the class to record observations.

WISE and the Public Idea Manager

The platform for our curriculum and technology development is the Web-based Inquiry Science Environment (WISE, wise.berkeley.edu). WISE is a free, open-source, and customizable online learning environment. With WISE, students engage in self-paced, collaborative investigations, in which they collect and interpret evidence from dynamic visualizations, and use various tools to express their understanding. WISE meanwhile logs students' interactions, which enables teachers to grade and give feedback, and designers and researchers to better study the impacts of technology on student learning.
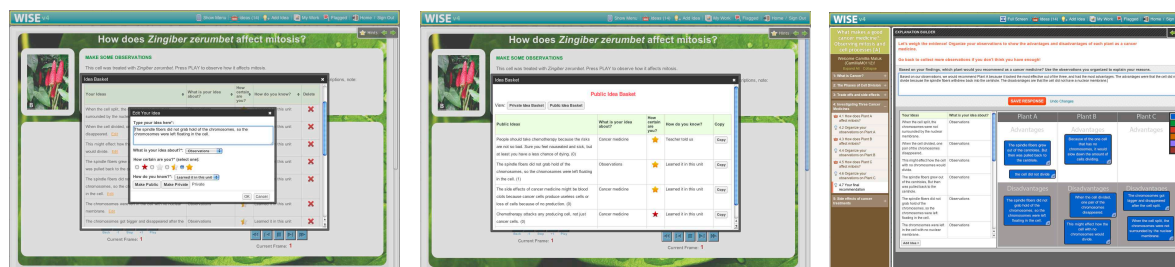
Figure 1. Over the course of a unit, students enter short text entries into their *Idea Baskets* (*left*), and specify attributes (e.g., source, tags, rating). Students can choose to share any private idea to the *Public Basket*, from which they may also copy any idea into their *Private Baskets*. Entries accumulate in a sortable list to which students can return and revise (*middle*). In the *Explanation Builder* (*right*), students drag ideas into author-defined categories, and refer to these as they write an explanation in response to a prompt.

The *Public Idea Manager* (Figure 1) is a feature of the *Idea Manager* (IM), a tool integrated into WISE. The IM scaffolds explanation according to the KI pattern by making explicit the acts of gathering, distinguishing, and sorting ideas (Matuk, et al., 2012). As WISE logs these actions, the IM provides teachers and researchers a record of students' changing ideas that can inform instruction and design. For example, prior research used the IM in a chemistry unit to identify when in the process of explaining students found specific

ideas more or less difficult to apply (McElhaney, et al., 2011). Such analyses indicate the kind of assistance needed, as well as which students need it. As such, the IM adds value over typical pre and posttests of students' understanding. The Public IM extends the functionality of the IM from a private repository to a common space through which students can exchange ideas. First piloted in classrooms as a hybrid prototype (Matuk, et al., 2013), this feature makes it possible to track how ideas emerge and spread within a classroom, and how exchanging ideas affects students' developing understanding.

The design of the Public IM was inspired by previous and existing argumentation and explanation scaffolds (e.g., Bell, 2004; Zhang & Quintana, 2012). By supporting freeform documentation, the tool allows for the various kinds of ideas students may have, which do not always conform to teachers' and designers' expectations. The interface of the Public IM is moreover customizable, including the selection of idea attributes, the categories for sorting, and the names *Idea Basket* and *Explanation Builder*. As such, teachers and researchers can adapt the tool to align with their own research and instructional goals.

Integrating the Public Idea Manager into *Mitosis*

What Makes a Good Cancer Medicine? (aka, *Mitosis*) is a middle school unit publicly available at wise.berkeley.edu (Preview the unit at http://wise.berkeley.edu/webapp/previewproject.html?projectId=6498). In it, students assist a fictional scientist in investigating the potential of three different plant-derived chemicals in treating cancer. This sequence of activities was designed to follow the Knowledge Integration pattern by structuring activities to support eliciting, adding, distinguishing, organizing, and reflecting on ideas as students prepare to write recommendations for cancer medicines based on their observations (Matuk & Linn, 2013).

As students examine animations to compare the effects of each chemical on cell division, they learn the phases of mitosis and cell division. At several points throughout the unit, students are prompted to gather ideas in the IM about specific topics (e.g., cell division, cancer medicine, observations made of the animations). At four different points in the unit, students sort their ideas in preparation to write explanations *(What happens when cells divide? How might a medicine stop cancer cells from dividing? Which treatment would you recommend?* and *Why does hair fall out during cancer treatment?)*. At these same points, students are encouraged to share at least one of their ideas to the Public Basket, and to copy at least one of the Public ideas into their Private Baskets. After each exchange, students are asked to write justifications for their choices of ideas.

Data and Analysis

Because this study is part of a larger research program on technology-enhanced curricula, we focus our analysis on just the relevant portion of all data collected. Specifically, our analysis aimed to explore how students exchanged ideas through the Public Idea Manager, and how the diversity of their ideas related to the quality of their explanations. Thus, we sought correlations in student log files on private ideas generated, private ideas shared to the Public Basket, and public ideas copied into students' Private Baskets. We analyzed students' written explanations to culminating questions in the final Idea Manager sequence of the unit, and analyzed their written justifications for exchanging ideas. Details of our analysis are described below. We triangulated this data with classroom field note observations, video of student pairs working together on the unit, and retrospective interviews with teachers, from which we selected cases to illustrate and explain our quantitative findings. Among other questions in the interviews, we asked teachers to reflect on students' uses of the tool, and to share their observations of its impact on students' learning and collaboration.

A pre and posttest included a paper-and-pencil test that asked students to draw and describe the phases of cell division, and a computer-based test with open-ended and multiple-choice questions that asked students to use their understanding of cell division to reason about the mechanism of an effective cancer treatment. These assessments were designed to measure the overall effectiveness of the unit on improving students' conceptual understanding of key ideas introduced in the unit. Each item was scored on a 5-point rubric that measured the degree to which students integrated ideas into a coherent explanation (Linn & Eylon, 2011).

Results

Pre and Post-Test Gains

Students showed significant average gains from the pre to the posttest (M=1.38, SD=1.09, $t(219)=-12.88$, $p<.0001$). This indicates that the unit had a positive impact on students' learning. In what follows, we discuss findings that illuminate students' uses of the Idea Manager.

How Did Students Exchange Ideas?

By the end of the unit, students' Private Baskets contained an average of 18.7 ideas (SD = 6.8). A significantly greater number of these ideas were self-generated (M=14.53, SD=5.52) than were chosen from the Public Basket (M=4.17, SD=3.42). This finding is encouraging because it suggests that in spite of their access to the

Public Basket, students were not reliant on their peers for ideas. Instead, they tended to start with ideas of their own.

Students appeared more inclined to contribute ideas to the Public Basket (M=5.11) than they were to copy ideas (M=4.26). They moreover appeared highly selective in the ideas they decided to exchange, as only 22.8 - 27.3% of the mean 18.7 ideas in their Private Baskets were ever in circulation. To determine whether students were making good decisions in their choices of Public Ideas, we scored each Public idea based on how well it integrated two or more relevant concepts into a supported statement (Table 1.)

Table 1. Scoring rubric for the quality of ideas in the Public Basket

| Score	Description	Example
0	No response	(None found)
1	Off task	(None found)
2	Uninterpretable; nonnormative ideas or observations;	They divide during mitosis because cancer cell make them spread the sickness.
3	Declarative or factual statements or definitions; unconnected ideas; or a mixture of normative and nonnormative ideas.	its bad, you can die, theres many types of cancer.
4	A normative observation or claim, but lacks interpretation, explanation, or sufficient supporting evidence.	The medicine stops the centrioles and spindle fibers from pulling the choromosomes apart.
5	Integrates more than one concept into a well-supported, normative claim; offers a causal explanation for an observation.	The cell was able to undergo mitosis, but one of the cell's chromosomes was obliterated by the Zingiber zerumbet, possibly making that cell useless.

Public ideas had a mean quality score of 3.77, and were copied a mean number of 0.83 times. Results show that higher quality public ideas also tended to have been copied more frequently ($F(2, 721) = 10.76$, $p<.0001$) (Figure 2). This finding suggests that students appear to successfully recognize good quality ideas from among those available in the Public Basket.
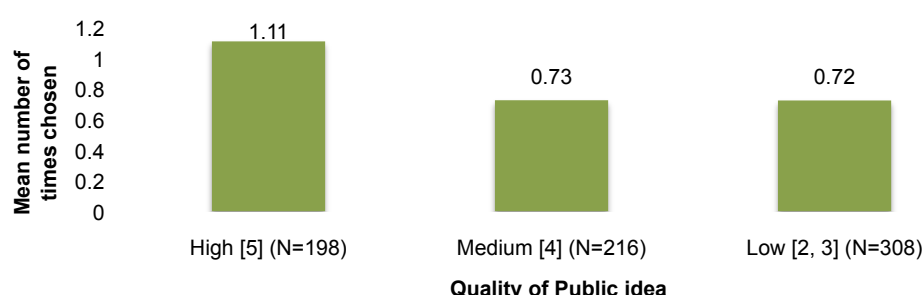
Figure 2. Students more frequently chose higher quality ideas than they chose medium or low quality ideas from the Public Basket. Quality scores are shown in square brackets.

Students' Reasons for Exchanging Public Ideas
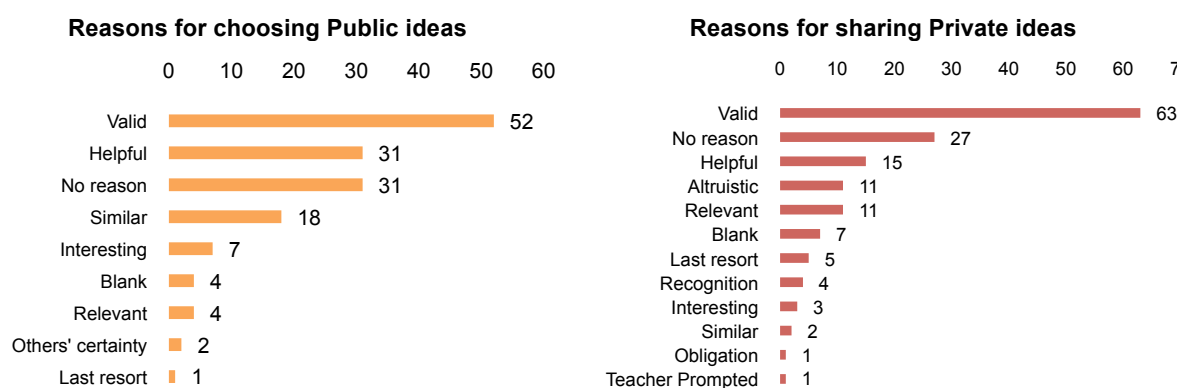
Figure 3. Categories of students' justifications for choosing and sharing ideas midway through the unit.

To explore whether students were consciously choosing ideas based on their quality, we examined their written responses to embedded prompts to justify their decisions. In these, students expressed a variety of reasons for

exchanging ideas in the Public Basket (Figures 3 and 4). Most commonly, students based their decisions to share and to copy ideas on the idea's perceived validity ("… because we agree with it the most." "…it was a very smart answer and it seemed like something that would be true.").

Reasons for sharing private ideas additionally included a desire for peer recognition ("...we wanted to… see what [our classmates] thought (if they [chose] our idea or not)."), and a desire to improve the Public Basket ("[our idea] seemed acurate [sic] compared to the other (students') ideas." "… we thought it was a good idea and nobody has it yet." "… it was a general statement that other classmates would understand."). Altogether, these findings suggest that students engaged in sophisticated decision-making when evaluating their ideas against those of their peers. In sharing ideas, some students even appeared to consciously consider the value of their contributions to this collaborative space.
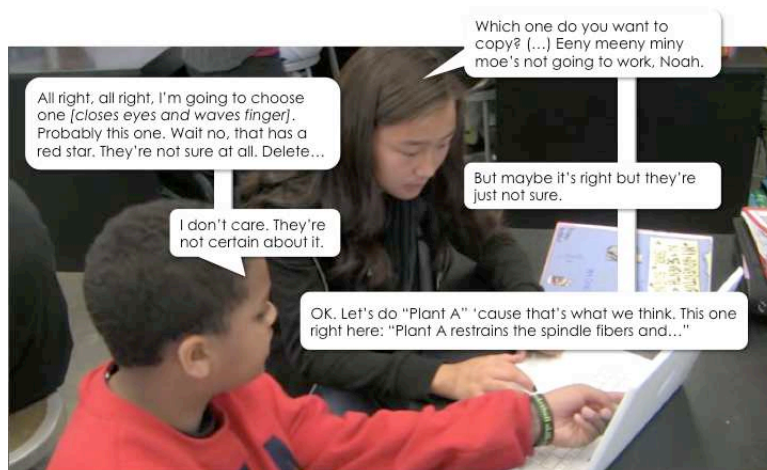

Figure 4. In choosing which Public idea to copy, these students consider various strategies, including random selection, the certainty of the idea's contributor, and the similarity of the idea to existing ideas of their own.

How do Idea Sources and Diversity Relate to Explanation Quality?

Notably, approximately 20.67% of students chose Public ideas because they were helpful; that is, because they added new information to their thinking ("… because it was well written and explained part of the lesson." "… because we thought that it was similar to our idea but different enough to provide food for thought."). In contrast, 12% of students chose ideas because of their similarity to existing private ideas ("…because we wrote a private idea similar to that…").

If students were indeed choosing Public ideas based on difference or similarity with respect to their own ideas, we might expect this to reflect in the actual diversity of students' Private ideas. The relative benefits of diversifying vs. converging on ideas might moreover be evident in the quality of students' explanations. Specifically, how well do students explain who tend to collect ideas that simply agree with their own? How well do students explain who tend to collect ideas that conflict with, or that otherwise diversify, their own ideas? To explore these questions, we coded each of students' Private Basket ideas according to whether it was unique or redundant relative to the rest of the ideas in the Basket. *Unique* ideas added new information not already present in the Basket, whereas *redundant* ideas restated already existing ideas. Results show that students' Private Idea Baskets contained a greater proportion of unique as opposed to redundant ideas, regardless of the source (i.e., self-generated or copied from the Public Basket) (Figure 5).
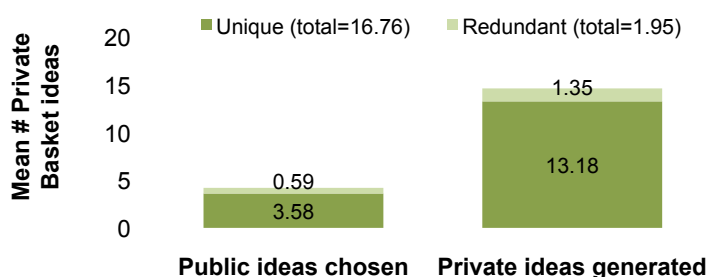
Figure 5. Proportion of unique and redundant ideas by source

To explore the relationship between idea diversity and students' abilities to explain, we scored students' explanations to the final prompt in the unit: "*Maya heard that her mother's hair might fall out during her cancer treatment. Why would this happen?*" Explanations were scored based on the number of links students made between key ideas presented in the unit (Table 2):

- Cancer is when cells divide rapidly/out of control.
- Cancer treatment stops cell division to treat cancer.
- Chemotherapy targets rapidly dividing cells.
- Chemotherapy also stops normal cells from dividing.
- Skin/hair cells are rapidly dividing cells.
- When hair cells aren't replaced with new ones, hair falls out.
- When skin/hair follicle cells die, they can no longer hold hair in the scalp and the hair falls out.

Table 2: Scoring rubric for explanations

Score	Description
0	Blank
1	Off-task, not possible to interpret
2	Non-normative, lacks explanation, doesn't address the question
3	1 normative idea
4	2 linked normative ideas
5	Elaborated response with 3+ linked normative ideas

Results show the relative diversity of ideas in students' Private Baskets to be correlated with the quality of their explanations at the unit's end. Specifically, students with the poorest explanations also tended to have a greater number of unique ideas in their Private Baskets, whereas students with the best explanations tended to have a greater number of redundant ideas (F(2, 142) = 6.04, $p<.005$) (Figure 6).
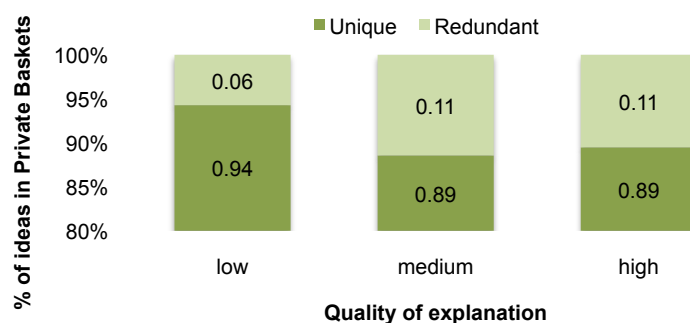

Figure 6. Proportion of unique and redundant ideas in students' Private Baskets, by explanation quality
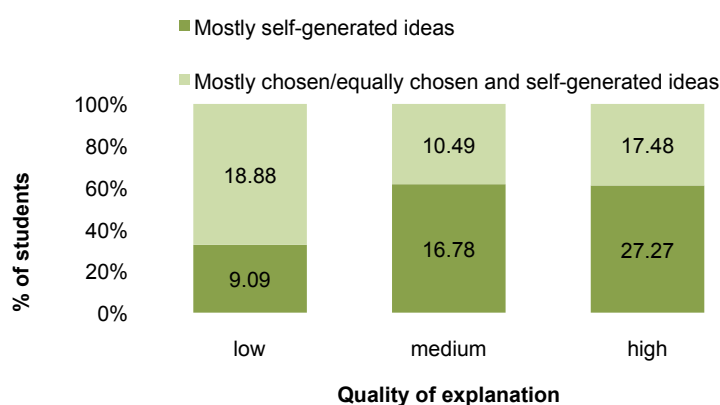

Figure 7. Sources of redundant ideas by quality of explanation

Further analysis shows a relationship between the quality of students' explanations and the sources of these redundant ideas: students themselves or their peers. That is, students who wrote better explanations also tended to have self-generated more of the redundant ideas in their Private Baskets. In contrast, students who wrote poorer explanations tended to have mostly chosen, or to have equally chosen and self-generated, their redundant ideas (χ^2 = 9.511, df = 2, p<.01) (Figure 7).

How the Public IM Enhanced Teachers' Roles

In her interview, one teacher noted how prior to this tool, she struggled to keep her students from simply relying on the smart kids to give the answers. Because of its anonymity, the Public Basket placed all students' ideas on equal footing. It was such that the teacher noticed that her students' discussions are more interesting" as they made serious attempts to consider and understand their peers' ideas.

The tool also helped teachers provide formative feedback. Instead of waiting until students had gone too far down a misguided path, teachers would scan through WISE's grading interface, notice how students were organizing their ideas, and identify students in need of individual assistance. Teachers would also monitor students' ideas to identify which topics appeared most challenging overall. Based on this information, teachers would tailor whole-class opener activities to reinforce the unit's instruction. Future work will explore visualization tools to help teachers more easily monitor patterns in students' ideas; as well as a feature that allows teachers and researchers to moderate students' exchanges, such as by seeding the Public Basket with ideas, or promoting promising ideas for other students to notice.

Discussion and Implications

Using a new tool for students to exchange ideas during web-based science inquiry, we found relationships between the sources and diversity of the students' ideas, and the quality of their explanations. Interestingly, students who had generated more redundant ideas also tended to have constructed more coherent explanations. One reason for this observation is that students who were already likely to produce high quality explanations managed to identify the key ideas early in the unit. These students may thus have tended to rephrase these same key ideas whenever prompted to add new entries. Meanwhile, students who were already likely to produce poor quality explanations may have been less able to recognize relevant, normative ideas. It follows that a highly diverse set of ideas may indicate students who need more support distinguishing among their many ideas.

Another explanation for this finding is that generating redundant ideas has cognitive benefits. It may help students refine their understanding, as does self-explanation (Chi, DeLeeuw, Chiu, & LaVancher, 1994; Siegler, 2002). Elaborating by rearticulating ideas may be a metacognitive learning strategy that involves actively creating links between new and prior knowledge (Mayer, 2002; Weinsten & Mayer, 1986). As with rewriting and revision, students who generate redundancy may be re-evaluating and clarifying their thinking (Ladd, 2003; Fitzgerald, 1992; Scardamalia & Bereiter, 1994).

An advantage of this tool is that it allows careful engineering of students' interactions with information, and thus, ways to explore variations in scaffolding the exchange of ideas. As analysis of these data continues, we are investigating the effects of prompting students to use the Public IM either to diversify or to reinforce their ideas, and how exposure to either diverse or redundant ideas might influence how students revise their explanations. Among other questions, we will explore when in the process of explanation (e.g., gathering, distinguishing, or sorting ideas), and for which students (e.g., low vs. high prior knowledge) each strategy might be most effective. We will also trace specific self-generated and copied ideas over time to see how these become integrated into students' explanations.

Revisions to the technology may include features that support effective discourse between students, and more deliberative choices around the exchange of ideas. Future research might explore how lessons learned about the role of technology in the exchange of ideas might be applied to different contexts, such as engineering design, medical decision-making, and other problem-based learning scenarios.

Learning and Becoming in Practice

This research relates to the theme of *Learning and Becoming in* Practice in multiple ways. First, it attends to the notion that science inquiry entails participation in a global knowledge community. This involves developing and practicing various collaborative skills, including expressing scientifically informed ideas, sharing ideas with peers, and evaluating multiple sources of information. Second, our study explored the role of technology in helping students thus engage meaningfully with information, and with each other. We observed how our tool supported teachers attending to their students' ideas throughout their inquiry, thus giving them the means to focus assessment on learning processes and on the development of scientific practices, rather than just on outcomes. Finally, our approach to design is one that emphasizes sustainability. By being customizable, for example, the Public IM allows both researchers and teachers to explore different questions about how students learn, and how to support it. By also involving various stakeholders in the design of the tool, our design process invites others to contribute to the tool's improvement. These features help maintain the tool's relevance, and ensure its usability and usefulness over time.

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