The Lifespan and Impact of Students' Ideas Shared During Classroom Science Inquiry

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Abstract: Sharing ideas can strengthen students' science explanations. Yet, how to guide uses of peers' ideas, and what the impacts of those ideas are on students' learning, are open questions. We implemented a web-based cell biology unit with 116 grade 7 students, and explored how peers' ideas are used during explanation building, and how prompts to draw on peers to either diversify or reinforce existing ideas impacted the quality of students' written explanations. Among other findings, exchanging ideas with peers led to all students improving their explanation quality upon revision; and students prompted to diversify their ideas showed greater learning gains by the end of the unit, while students prompted to reinforce ideas, who used more peer-generated ideas in preparation to write their explanations, produced higher quality explanations. This study builds our understanding of the influence of peer ideas on learning, and offers insight into supporting students in engaging effectively with peers' ideas.

The role of peer ideas in knowledge integration

Because scientific knowledge is socially constructed (Latour & Woolgar, 1979; Lemke, 1990), the ability for science learners to engage productively with one another's ideas is critical to develop, as is their ability to refine explanations and arguments in light of new ideas (NGSS Lead States, 2013; Kuhn, 2012). Nurturing a culture around sharing and improving collective understanding can position students as creators, rather than just readers of knowledge (Scardamalia & Bereiter, 2014). However, research is mixed on the best ways to support students' encounters with others' ideas (De Jonge, 2018). For example, one study documented how the ideas that middle school students collected during their inquiry investigations related to the quality of their later scientific explanations. Specifically, students' tendencies to find ideas that reinforce, as opposed to diversify their existing repertoire of ideas before writing an explanation, and their tendencies to self-generate those ideas rather than to use peer-generated ideas, also resulted in them writing stronger scientific explanations (Matuk & Linn, 2018). Another study suggests that diversifying rather than reinforcing ideas is a more successful strategy for students of higher prior knowledge than it is for students of lower prior knowledge (Matuk & Linn, under review). These findings begin to suggest how different ways of engaging with peers' ideas can support students' own thinking; and for whom these ways may be more or less productive.

Our research is guided by the Knowledge Integration (KI) framework (Linn & Eylon, 2011), a perspective based in research in the learning sciences, and that views learners as constructing understanding by distinguishing among various new and existing ideas. KI instruction supports learning by eliciting students' existing ideas, assisting them in distinguishing these from newly encountered ideas, and organizing these into a coherent understanding. However, the role of peers in knowledge integration is less clear. Little work has focused, for example, on the lifespan of shared ideas in a classroom. That is, when students share ideas, which types of ideas are taken up and used throughout the course of students' inquiry? How do these shared ideas support students in constructing sound explanations? Moreover, what strategies for using these ideas might be more or less effective?

This study extends prior research by exploring the kinds of ideas that students exchange during inquiry, and ultimately incorporate into their explanations. It also explores the value of different strategies for using peers' ideas on the quality of their explanations, and on their overall learning outcomes.

Research questions

We implemented a web-based science inquiry unit in a middle school classroom, which features a tool that supports students in sharing ideas with classmates as they work toward constructing scientific explanations. Our specific research questions are:

1. What overall impact does the unit have on students' conceptual learning? How does prompting students to seek similar vs. different ideas from peers impact their overall learning?

2. How does prompting students to seek similar vs. different ideas from peers impact the quality of

students' explanations?

3. What is the trajectory of ideas across students' explanation building process? That is, how did students take up and incorporate their peers' shared ideas? Which kinds of ideas were more popular? How did peers' ideas impact the quality of students' explanations?

Methods

WISE and the Idea Manager

The Web-based Inquiry Science Environment, or WISE (wise.berkeley.edu) is a free, open-source platform created to design and deliver classroom-based science inquiry curriculum (Slotta & Linn, 2009). The Idea Manager is a tool integrated into WISE to support students in collecting, distinguishing, and organizing their ideas into coherent science explanations during their inquiry investigations (Matuk et al., 2016). Following the KI framework, the Idea Manager offers a persistent space called the *Private Idea Basket*, within which students can document their existing and new ideas in brief entries; sort and distinguish among these ideas using a visual organizer called the *Explanation Builder*; and refer to their organized ideas to integrate them into a written explanation (Figure 1). Students can choose to add any of their idea entries to a *Public Basket*, which anonymously lists all ideas shared by students in the same class. Students can select publicly shared ideas to "copy" into their own Private Baskets. Thus, peer-generated ideas become available for use alongside students' self-generated ideas.
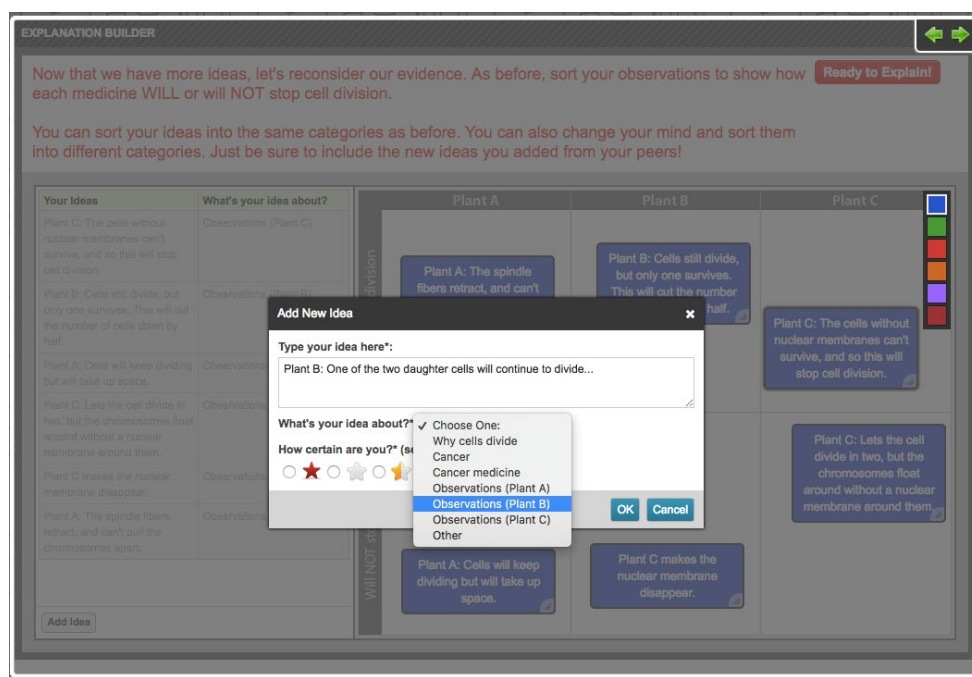

Figure 1. Foreground: An idea entry dialog box. Background: the Explanation Builder, in which students organize ideas, then refer to them to write an explanation (by clicking the "Ready to Explain" button).

The *Mitosis* unit

The unit, *What makes a good cancer medicine?: Observing mitosis and cell processes* (*Mitosis*), introduced students to the process of cell division and its relationship to cancer and cancer treatment. Animations, diagrams, and narrative explanations introduced students to the phases of normal cell division, and to the notion that cancer is a disease in which cells have lost the mechanism that controls their division. An effective cancer treatment must thus stop cancerous cells from dividing, but this does not occur without side effects.

Students then compared the effectiveness of three potential, plant-derived cancer medicines. They viewed animations of dividing cells that were treated by each medicine, and noted their observations in their Private Idea Baskets. Following this, they organized their ideas in the Explanation Builder to sort pros and cons for each medicine, and then referred to these ideas to write an explanation for the medicine they recommended.

Students were then asked to make public the ideas they used in their recommendations, and to select public ideas from their peers to add to their own Idea Baskets. They then reorganized their previously and newly

added ideas within the Explanation Builder and referred to these to revise their recommendations (Figure 2).
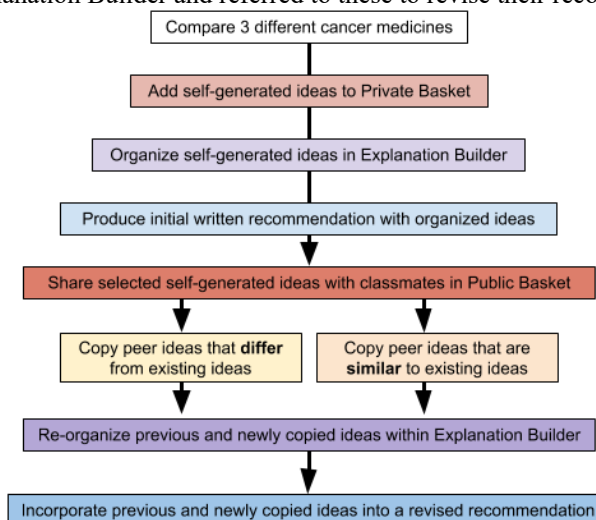

Figure 2. The *Mitosis* activity sequence and study design.

Participants and study design

Participants were 144 grade 7 students across 5 class periods of one teacher, from a diverse public middle school on the West coast of the United States. Students worked on the unit in pairs at their own pace during class time for 10 consecutive school days. The teacher, who had 5+ years of experience teaching with WISE, circulated to assist students, led occasional whole class discussions to address common conceptual challenges, and offered guidance on upcoming unit activities. Collaboration occurred at different levels: First, by working on shared computers, student partners had to come to consensus through discussion over their responses. Second, the teacher regularly reminded students to document and share their ideas with others in class, such as by pointing out good ideas during her conversations with partners, and encouraging them to add these to the Public Basket.

Students individually completed a pre and posttest on the first and last days of the study. One of the three items on this pre/posttest addressed students' understanding of the order and importance of the phases of cell division. A second item tested their ability to apply this understanding to reason about the action of an effective cancer medicine. A third item asked students to select ideas from fictional peers that would help them to write an explanation for the role of spindle fibers during cell division.

To investigate the value of different strategies for using peers' ideas, students were divided into two conditions. In the Reinforce condition (N=66 students, 36 workgroups), students were prompted to collect peer ideas that were similar to their own ideas. In the Diversify condition (N=50 students, 27 workgroups), they were prompted to collect peer ideas that differed from their own. We excluded from our analysis students who had not completed the pre/posttest, nor submitted both initial and revised recommendations. The total number of students in our dataset was therefore 116.

Data and analysis

Data consisted of each workgroup's individual ideas, including information on which ideas they kept private and which they made public, which public ideas were copied by which workgroups, and which ideas were used in students' Explanation Builders. We also collected students' initial and revised written recommendations and their responses to the pre/posttest.

To determine differences between conditions in the overall impact of the unit on students' learning outcomes (RQ1), we scored students' pre and posttests based on previously developed KI rubrics, which give credit to responses that integrate key ideas (Matuk & Linn, 2018). Two independent raters achieved high inter-rater reliability across the three items (κ=0.91, 0.83 and 0.71). We summed scores across items to obtain a total score for each student, and used a t-test to detect differences in mean total scores between conditions.

To compare the effects on students' recommendations of prompts to seek peer ideas that differed and that resembled their own (RQ2), we scored students' initial and revised recommendations. One rubric identified the presence of *Key Concepts* (Table 1) and another rated the *Argument Structure* (Table 2), while the sum of the scores on these two criteria produced an overall score out of 10 of the explanation's quality. Two independent raters scored 20–30 student responses at a time, and resolved disagreements through discussion

until inter-rater reliability had been achieved (*Key Concepts* κ=0.83; *Argument Structure* κ=0.96). We used t-tests to detect differences in students' gains on the individual *Key Concepts* and *Argument Structure* dimensions, and on their overall explanation quality, between workgroups' initial and revised recommendations, and between the Reinforce and Diversify conditions.

Table 1: Rubric for identifying *Key Concepts* in students' initial and revised recommendations

Key Concepts
- *Org:* Identifies a cell organelle to be affected by the medicine (e.g., chromosomes, spindle fibers).
- *Process:* Explains the manner by which the medicine will disrupt the organelle's function (e.g., will prevent chromosomes from dividing).
- *Need:* Mentions that the medicine must stop cell division/cancer growth in order to treat cancer.

Score	Criteria	Examples
0/1	No Answer/Offtask or uninterpretable	(Blank)/I don't know.
2	Irrelevant, incorrect or ambiguous	We think plant A will work the best because it kills off the cell without leaving with empty cells that clog the body which is what cancer does as well.
3	Any ONE of the three key ideas is correctly explained.	I think that the best cancer medicine is plant A, because it will stop the cell from undergoing mitosis *[Need]*. It will stop the the [sic] cell from ever doing mitosis, but the cell might still be able to survive.
4	Any TWO of the three key ideas are correctly explained.	We will recommend plant A because it stopped the spindle fibers *[Org]* from working before a new cell was created therefore it stopped mitosis *[Need]*.
5	All THREE key ideas are correctly explained.	Plant A because it is the most effective at stopping mitosis *[Need]*. The pros to this plant is that the spindle fibers *[Org]* don't go all the way so mitosis isn't complete. So if the spindle fibers don't go all the way *[Fxn/Process]* through then the chromosomes *[Org]* won't line up *[Process]*. The cons are that their will be side effects from the medicine.

Table 2: Rubric for evaluating the *Argument Structure* of students' initial and revised recommendations

Score	Criteria	Examples
0/1	No Answer/Offtask or uninterpretable	(Blank)/I don't know.
2	Claims stated with no supporting evidence.	I think Plant A is most effective.
3	Interpretation given that includes a claim supported by evidence, which may or may not properly align. No counter-arguments are given.	we think that the most effective cancer medicine is plant A due to the fact that it stopped the spindle fibers from growing and the spindle fibers will not grow to redirect the chromosomes *[supported interpretation]*
4	Interpretation given that includes a claim aligned with supporting evidence. Offers unelaborated counter-arguments (e.g. pros/cons, side effects, comparison to alternatives).	Plant A because it is the most effective at stopping mitosis *[supported interpretation]*. The pros to this plant is that the spindle fibers don't go all the way so mitosis isn't complete. So if the spindle fibers don't go all the way through then the chromosomes won't line up. The cons are that their will be side effects from the medicine *[unelaborated counterargument]*.
5	Interpretation given that includes a claim aligned with supporting evidence. Offers at least one elaborated counter-argument (e.g. pros/cons, side effects, or comparison).	We think that medicine A is the best because it stops the cell from dividing, which would work the best *[valid interpretation]*. Medicine B only destroys the second pair of chromosomes, which means when the medicine wears off, the cell can split again. Medicine C only destroys the cells' membranes which means that the cells might still be able to split *[elaborated counterargument]*.

To track the trajectory of ideas (RQ3), we gave each idea a unique "private idea ID" that indicated the workgroup that had generated it; and each copied idea a unique "copied idea ID" that indicated the workgroup that copied it. These IDs allowed us to identify the trajectory of each idea from its origin, to its sharing in the Public Basket, and to its use in an Explanation Builder step. Finally, we used these IDs to note which ideas were

present in students' written recommendations. We used t-tests to detect significant differences in students' engagement with ideas across the unit. We also tested how the proportion of peer- vs. self-generated ideas impacted the quality of students' revised recommendations.

Because students were collecting ideas to construct arguments for the medicines they recommended, we characterized the ideas in terms of three main components of an argument: *Claim*, *Observation*, and *Interpretation* (Table 3). These categories are based on theories of argument structure, which describe the function of argument to be in creating links between claims and evidence (Burleson, 1979; Kneupper, 1979; Toulmin, 2003). Two independent raters scored 20 ideas at a time until they had achieved Cohen's kappa values of 0.83, 0.90, and 0.83 on *Claim*, *Observation*, and *Interpretation*, respectively. One coder then categorized the rest of the ideas. We excluded from our analyses nine of the ideas that were irrelevant to the task of constructing a recommendation (e.g., "Three plant idea").

We determined the relative *popularity* of ideas by the number of times these were copied by other workgroups. We then used an ANOVA to uncover associations between the kinds of ideas and their popularity.

Table 3: Scoring rubrics for distinguishing ideas as Claim, Observation, and Interpretation

Type	Description	Example
Claim	Declarative, factual statements not supported by evidence from the unit.	Cancer is the overgrowth of cells. It can travel down the body in the blood stream.
Observation	Descriptions, without accompanying inferences, of information from the unit (e.g., of animations).	The treated cell's spindle fibers stopped. They didn't grab the chromosomes. They're also green.
Interpretation	Causal/explanatory statements or inferences that integrate ideas that are not otherwise explicit in the unit.	The mitosis is not prevented but slowed down because the daughter cells wont be able to divide.

Findings

RQ1: How did the unit impact students' learning overall?

The unit as a whole appeared to positively impact students' conceptual learning. All students showed significant gains between the pre and posttest (N=116; M=3.16; SD=2.27; t(115)=15.00, p<.001, d=1.63). Prompts for students to use peers' ideas to diversify their own ideas seemed to be particularly beneficial, as students in the Diversify condition (N=50; M=3.74; SD=2.26) showed significantly greater gains than students in the Reinforce condition (N=66, M=2.73, SD=2.20), t(114)=-2.43, p=.017, d=.45).

RQ2: How did exchanging ideas impact students' written explanations?

Students' overall recommendations improved significantly upon revision following their exchange of ideas with their peers (M=1.14; SD=1.80; t(62)=5.05, p<.001, d=.75). In both conditions, students' final recommendations reflected more key concepts (M=0.57, SD=1.04, t(62)=4.35, p<.001, d=.58) and better argument structure (M=0.57; SD=0.14; t(62)=4.11, p<.001, d=.65) than their initial recommendations. There was no significant difference in the overall explanation quality between the Reinforce condition (M=8.94, SD=1.59, N=36) and the Diversify condition (M=8.78, SD=1.37, N=27), t(61)=0.438, p=.663, d=.108. There were also no significant differences in gains between the Key Concepts and Argument Structure criteria within nor between conditions. These findings suggest that exchanging ideas generally had a positive impact on students' revisions, regardless of the manner by which students were prompted use their peers' ideas.

RQ3: What was the trajectory of ideas across the unit?

How did students take up and incorporate their peers' ideas into their explanations?

To understand the overall trajectory of self- and peer-generated ideas, we graphed the average number of ideas at six time points (Figure 3). These included the ideas before and leading up to the initial recommendation, specifically, the ideas (1) generated in students' Private Baskets (Reinforce, M=7.33; Diversify, M=8.66); (2) organized in the Explanation Builder (Reinforce, M=5.02; Diversify, M=5.22); and (3) incorporated into the initial written recommendations (Reinforce, M=2.22; Diversify, M=2.55). Following students' exchange of ideas with their peers, we tracked (4) the copied ideas that students added to their Private Baskets (Reinforce, M=3.86; Diversify, M=3.33); as well as the additional private ideas generated at this point (Reinforce, M=7.58; Diversify, M=8.99); (5) the private ideas re-organized in their Explanation Builders (Reinforce, M=4.61; Diversify, M=4.88); and the copied ideas organized alongside them (Reinforce, M=2.08; Diversify, M=2.33).

Finally, we noted (6) which self-generated ideas (Reinforce, M=3.16; Diversify, M=3), and which peer-generated ideas students incorporated into their revised recommendations (Reinforce, M=1.69; Diversify, M=1.18).

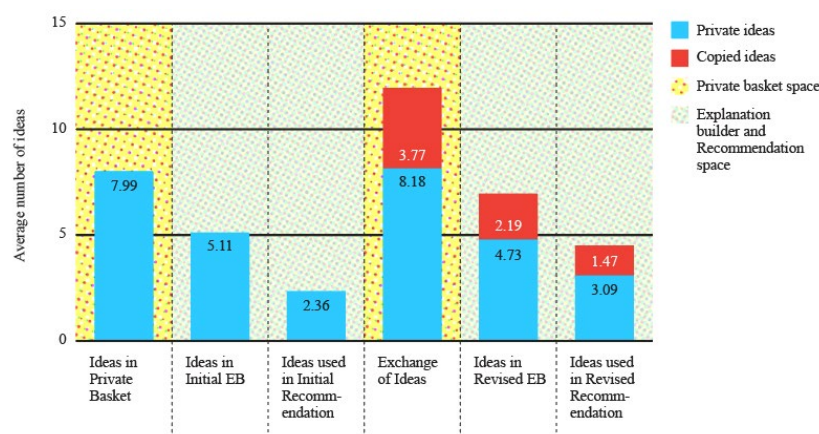
Figure 3. Trajectory of ideas generated by students (N=63 workgroups) across both conditions. (EB=Explanation Builder)

Figure 3 shows that across conditions, students generated more ideas (M=7.9) than they organized in their Explanation Builders (M=5.11), and used in their initial recommendations (M=2.38). This same pattern is seen in students' uses of their peers' ideas. Specifically, students copied more of their peers' ideas (M=3.77) than they organized in their Explanation Builders (M=2.19), and incorporated into their revised recommendations (M=1.47). Notably, students also generated more (M=8.18), and incorporated more of their own ideas, as opposed to their peers' ideas, into their revised recommendations (M=3.09) following their exchange with their peers.

Compared to students' uses of ideas leading up to their initial recommendations, students added more ideas to their Private Baskets (N=63; M=4.06; SD=3.33; t(62)=6.70, p<.001, d=.88), organized more ideas in their Explanation Builders (N=63; M= 1.81; SD=1.87; t(62)=7.70, p<.001, d=.72), and incorporated more ideas into their final recommendations (N=63; M=2.21; SD=0.25; t(62)=8.68; p<.001, d=1.01) following their exchange of ideas with peers. Students also used significantly more self-generated than peer-generated ideas in their revised Explanation Builders (N=63; M=2.54; SD=2.75; t(62)=7.43, p<.001, d=1.29) as well as in their revised recommendations (N=63; M=1.62; SD=2.22; t(62)=5.80, p<.001, d=0.99) compared to the steps leading up to their initial recommendations.

These patterns suggest that students were discerning in the ideas they chose to incorporate into their explanations, a finding that supports the knowledge integration process of distinguishing and sorting among ideas to find the most relevant ones. They also suggest that students used their peers' ideas to complement, rather than to supplant, their own ideas, which attests to the success of the Idea Manager in enabling students to draw upon their peers as supports, rather than being reliant upon them in building explanations.

Which ideas were most popular?

Across both conditions, *Observations* was the most frequently generated kind of idea (73% Reinforce; 63% Diversify), followed by *Interpretations* (15% Reinforce; 28% Diversify) then *Claims* (12% Reinforce; 18% Diversify). *Observations* was also the most highly copied kind of idea (Reinforce, M=2.08; Diversify, M=1.93), and significantly more so than either *Interpretations* (Reinforce, M=2.00; Diversify, M=1.18) or *Claims* (Reinforce, M=0.50; Diversify, M=0.59), (F(2,186)=3.99; p=.020) (Figure 4).

It may be that students found observations to be the most persuasive, and *Claims* to be the least robust kinds of peer ideas. For example, the most popular *Claim* across our dataset, copied just 4 times, was "there would be only half as many cells." This idea, which refers to the effect of one of the three medicines on cell division, offers neither supporting evidence, nor an explanation of the consequences of having "half as many cells." Students may thus have regarded it as being of little use for strengthening their own explanations. In contrast, students may have viewed Interpretations, particularly from their peers, to not be as trustworthy as a teacher's explanation, for example. For instance, the most popular Interpretation, copied 8 times, was "Plant A is good because it stops mitosis before it reaches anaphase." This idea offers an explanation, albeit a limited one, for why Plant A is the favored medicine. However, it also offers little detailed evidence, such that students

might be required to trust it at face value. Meanwhile, students may have found observations to be most easily grasped because they could verify these themselves by examining evidence in the unit. For example, the most popular Observation, copied 21 times, was "the plant chemicals don't stop the division of the cell. the chemicals get rid of the copy of the chromosome so the daughter cell has no chromosomes." This idea articulates observable events from the animations, which may either offer students new language to rearticulate their existing observations, or highlight details that they might have initially overlooked.
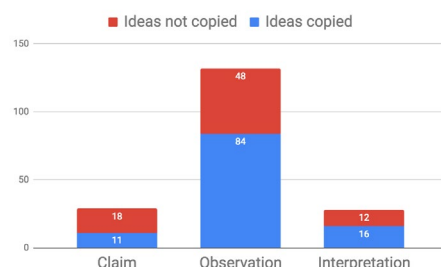

Figure 4. Totals of each kind of idea shared within the Public Idea Manager, and the proportion of ideas that were copied vs. not copied by students across both conditions.

How did peers' ideas impact the quality of students' explanations?

Students in the Reinforce condition who organized a greater proportion of peer- vs. self-generated ideas in the Explanation Builder tended to produce higher quality recommendations, that is, recommendations with scores of 9 or more out of 10, t(35)=-2.18, p=.036, d=.78. For students in the Diversify condition, however, the relative proportion of peer- vs. self-generated ideas did not have a significant impact on the quality of their explanations (t(26)=1.00, p=.327, d=.38). This finding suggests a benefit of organizing peer ideas that reinforced students' existing ideas.

However, there was no relationship between the proportion of self-generated and peer-generated ideas used in students' recommendations and the quality of those recommendations. This suggests that students' improved recommendations were not simply because of access to their peers' ideas, but more likely because of the effort they put into integrating their own and their peers' ideas into their explanations.

Figure 5 shows two examples of how students in each condition used their peers' ideas to improve their recommendations. In both cases, peers' ideas helped to elaborate recommendations with evidence and to strengthen arguments with counter-arguments.
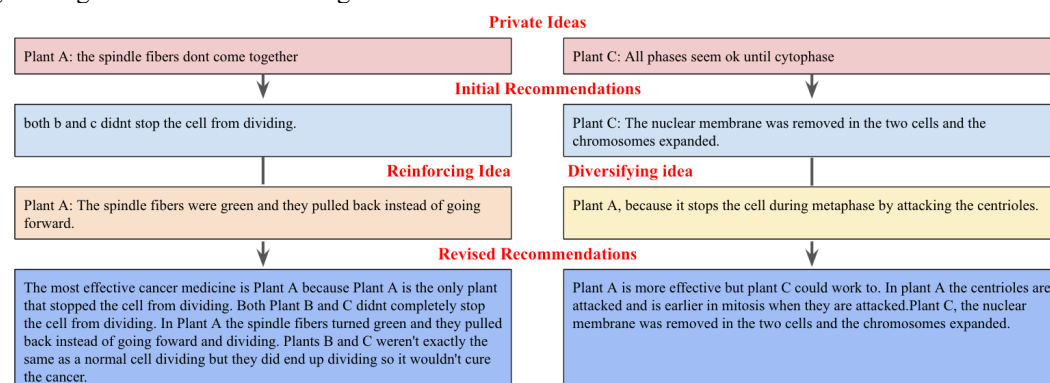

Figure 5. Examples of students' self-generated ideas, ideas chosen from peers, and initial and revised recommendations. (Left: Workgroup 119924; Right: Workgroup 119945)

Discussion and significance

Whereas the unit benefited all students' learning overall, students prompted to diversify their ideas gained significantly more. Meanwhile, students prompted to reinforce ideas, and who relied more so on peer-generated ideas than on self-generated ideas, produced higher quality in-unit explanations. These findings resonate with prior mixed research on the relative value of diversifying vs. reinforcing ideas. For example, encountering diverse ideas can improve conceptual learning (e.g., Asterhan & Schwarz, 2009; Matuk & Linn, 2018). At the same time, encountering one's own ideas rearticulated by others can prompt students to revise and improve their own ideas (e.g., Matuk & Linn, 2008; Edge, 2006; Hayes, 2004). Other work suggests that the benefits of reinforcing and diversifying ideas may differ for students with high vs. low prior knowledge (e.g., Matuk &

Linn, under review). Findings from this study suggest that in addition to different students benefiting from different prompts, students may also benefit at different times while building explanations.

Continued analyses might investigate whether there were pre-existing differences between conditions (e.g., prior knowledge) that would offer alternative explanations for our findings, and also whether students actually followed prompts to choose either diversifying or reinforcing ideas. Further research might explore how different students (e.g., high vs. low prior knowledge) benefit from different prompts to use their peers' ideas; and how various strategies (e.g., collecting mostly interpretations vs. observations) impact their success in explanation building.

Visualizing the trajectory of peers' ideas throughout the unit offered insights into the kinds of ideas that students were more or less likely to copy. Importantly, prompts to diversify or to reinforce ideas had no apparent effect on the ways that students used ideas throughout their inquiry. Continued analyses will investigate how the kinds of ideas generated, organized, and used, impact the quality of students' explanations. Future research might also explore other ways to characterize ideas besides in terms of the components of the argument. For instance, we might explore which science concepts are more or less challenging for students to identify at different stages of explanation (cf. McElhaney et al., 2012). Finally, we might examine the role of the teacher in conjunction with technology, in supporting students' productive interactions with peers.

In all, exchanging ideas with peers appeared to positively impact both students' written explanations and their overall learning outcomes. This study adds nuance to the literature on learning from peers. It moreover has implications for technology-rich knowledge sharing supports in classroom-based science inquiry.

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