Using the Idea Manager to Promote Coherent Understanding of Inquiry Investigations

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Abstract: This study examines the ideas students generated during an online inquiry investigation and how students used these ideas to construct scientific explanations about everyday phenomena. We designed and implemented a four-day, technology-enhanced inquiry unit on the chemistry of recycling with 164 high school students. The unit incorporates the *Idea Manager*, a new inquiry scaffolding technology that helps students record their ideas and construct coherent explanations. We scored the conceptual content of the ideas students recorded, how students organized their ideas, and the coherence of students' explanations. Regression models show that students' ability to distinguish ideas predicted explanation coherence more strongly than the number of relevant ideas they recorded. Three cases illustrate difficulties some students had using molecular concepts to support their explanations. The findings demonstrate how this new technology can permit closer examination of students' learning progress and inform curricular refinements.

Introduction

How do students integrate the range of ideas they hold into coherent scientific understanding while engaged in inquiry investigations? We investigate this question by studying how students collect, manage, and organize their ideas before they generate scientific explanations. We study a four-day inquiry unit titled *How Can We Recycle Old Tires?* (henceforth *Tires*) designed using the Web-based Inquiry Science Environment (WISE, Linn, Davis, & Bell, 2004). *Tires* features the *Idea Manager*, a powerful, new computer-based scaffolding technology that supports students as they manage ideas they generate from diverse sources and construct scientific explanations or arguments based on those ideas. Log files from the *Idea Manager* document how students assemble their ideas into coherent understanding as they progress through *Tires*.

Tires addresses difficulties students have with integrating observable and sub-microscopic phenomena. The design of *Tires* is based on the Knowledge Integration framework and guided by design principles that have emerged from empirical studies (Kali, 2006; Linn & Eylon, 2011). *Tires* has been iteratively refined through multiple classroom trials. *Tires* scaffolds scientific inquiry by eliciting students' everyday ideas and experiences with observable phenomena, guiding students' interactions with molecular visualizations, providing opportunities for students to illustrate and animate their ideas, and prompting students to generate scientific explanations and reflect on their understanding. *Tires* takes advantage of the *Idea Manager* to help students bring diverse ideas together into coherent accounts of science.

This study examines the nature and trajectories of students' ideas (as illustrated by the *Idea Manager*) and connects the evolution of students' ideas to the quality of their scientific explanations. We address two main research questions: (1) How do students integrate chemistry ideas about observable and molecular phenomena to achieve coherent understanding during inquiry investigations? and (2) How can technology-based inquiry scaffolding help students use chemistry concepts at the molecular level to explain observable phenomena?

Rationale and *Idea Manager* Design

Chemistry students struggle to integrate concepts at the observable and sub-microscopic levels (Johnstone, 1993; Kozma, 2003). Textbooks and typical classroom chemistry instruction add many ideas at the molecular level to students' repertoire of ideas but provide students with few opportunities to link their understanding of these molecular concepts to their everyday understanding of the world. As a result, students may gain proficiency at recalling isolated facts at the sub-microscopic scale but fail to make meaning of them.

Technology-enhanced inquiry investigations that help students bridge the gap between their everyday observations and ideas in the discipline show promise for helping students link observable and sub-microscopic concepts in chemistry (e.g. Schank & Kozma, 2002; Wu, Krajcik, & Soloway, 2001). Inquiry investigations compel students to integrate ideas having diverse origins such as everyday experiences, classroom instruction, scientific visualizations, experiments, and peer discussions. Research on inquiry instruction seeks effective scaffolds that help students achieve coherent understanding using diverse inquiry activities such as predictions, experiments, explanations, debate, and reflection (e.g. Linn & Eylon, 2011; Quintana et al., 2004).

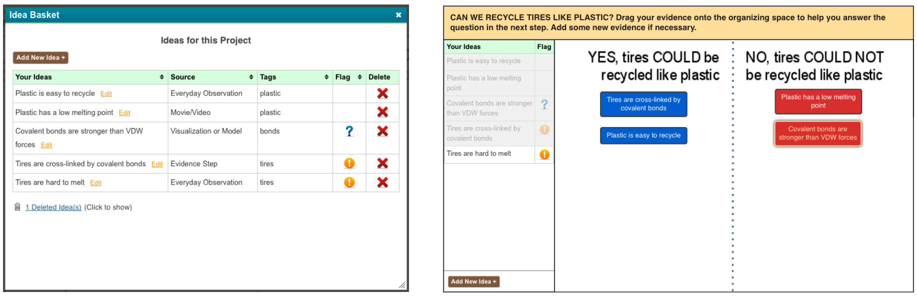
Furthermore, while studies examining inquiry investigations often demonstrate powerful learning outcomes as measured by pretests and posttests, pinpointing precisely how individual inquiry activities contribute to students' understanding has proven difficult. While comparison studies can shed light on the value of individual design features (e.g. Davis, 2003), researchers also need subtle embedded assessment methods to detect the contribution of each activity to students' progress.

We have designed the *Idea Manager* tools (Figure 1) to support students' learning from complex inquiry activities and capture the individual and cumulative contributions of these activities to students' learning. The *Idea Manager* consists of two interconnected tools, the *Idea Basket* and the *Explanation Builder*. The *Idea Basket* is a persistent repository for students' ideas during WISE investigations. The *Basket* reduces demands on students' memories and allows them to direct their efforts toward critically examining their ideas. Students add ideas (of up to 150 characters) to the *Basket* and can view, revise, and sort the *Basket* contents at any time. Embedded instructions can also prompt students to submit ideas to the *Basket* at specific points during the investigation. Students specify attributes of each idea entry, such as its source, tags, or flags (e.g. "Important" or "Not Sure"). WISE logs the attributes and time stamps of students' *Basket* interactions to reveal detailed information about the evolution of students' ideas.

The *Explanation Builder* addresses difficulties students have using evidence to support explanations (McNeill & Krajcik, 2008; Sandoval & Millwood, 2005) by scaffolding the explanation process into several manageable steps. Rather than asking students to generate complex explanations by having to recall diverse pieces of evidence from memory, The *Explanation Builder* presents students with the *Basket* contents and prompts students to organize their ideas in response to an inquiry question. Students drag and drop their ideas from the *Basket* to an appropriate part of the organizing space. Students can then construct an explanation based on their organized evidence. This approach thus scaffolds the process of constructing complex explanations that require diverse pieces of evidence collected over an extended time. WISE logs the identity and coordinates of each idea that students drag to the organizing space.

The *Idea Manager* tools build on the design of other scaffolds that support the management of inquiry evidence and the construction of evidence-based explanations and arguments, such as SenseMaker (Bell & Linn, 2000), ExplanationConstructor (Sandoval & Reiser, 2004), and IdeaKeeper (Quintana & Zhang, 2004, April). The *Idea Manager* differs in that it is designed to support the Knowledge Integration pattern (Linn & Eylon, 2011), which helps students integrate ideas across multiple scientific contexts. The Idea Basket encourages students to track both their current and new, normative scientific ideas. Meanwhile, the Explanation Builder helps students organize, distinguish, refine, and reflect on their *Basket* entries. Ultimately, these activities can help students construct more complete and coherent arguments and explanations.

Because the *Idea Manager* captures students' ideas at many points during an inquiry unit, it provides a window into how the students' understanding evolves over the course of an investigation. In this paper, we analyze how students generated scientific ideas and used these ideas as evidence in scientific explanations in *Tires*. Using logs of students' interactions with the *Idea Manager*, we examine how students' explanations incorporate the conceptual content of the ideas they accumulated during the investigation. The *Idea Manager* captures sustained reasoning as students assemble their diverse ideas into accounts of chemical processes during several days of classroom instruction. We evaluate students' explanations for coherence and completeness.



Ideas for this Project

Your Ideas	Source	Tags	Flag	Delete
Plastic is easy to recycle Edit	Everyday Observation	plastic		✕
Plastic has a low melting point Edit	Movie/Video	plastic		✕
Covalent bonds are stronger than VDW forces Edit	Visualization or Model	bonds	?	✕
Tires are cross-linked by covalent bonds Edit	Evidence Step	tires	!	✕
Tires are hard to melt Edit	Everyday Observation	tires	!	✕

1 Deleted Idea(s) (Click to show)

CAN WE RECYCLE TIRES LIKE PLASTIC? Drag your evidence onto the organizing space to help you answer the question in the next step. Add some new evidence if necessary.

Your Ideas	Flag
Plastic is easy to recycle	
Plastic has a low melting point	
Covalent bonds are stronger than VDW forces	?
Tires are cross-linked by covalent bonds	!
Tires are hard to melt	!

YES, tires COULD be recycled like plastic	NO, tires COULD NOT be recycled like plastic
Tires are cross-linked by covalent bonds	Plastic has a low melting point
Plastic is easy to recycle	Covalent bonds are stronger than VDW forces

Figure 1. Screenshots of students' views of the Idea Basket (left) and Explanation Builder (right).

Curriculum Design: *How Can We Recycle Old Tires?*

Tires helps students distinguish (1) the nature of covalent bonds from intermolecular attractions (e.g. van der Waals forces) and (2) the properties of tire rubber from recyclable plastics. Tire rubber is a polymer (natural rubber) strengthened by the addition of cross-linking covalent bonds. These bonds make tires sufficiently strong to be used on cars but also make tire rubber difficult to recycle. Plastics lack these additional covalent bonds; the weakness of the intermolecular forces holding plastic molecules together makes most plastics easy to recycle. By contrasting the atomic structure, bonding arrangements, properties, and recycling methods of tires and plastics, *Tires* guides students to make sense of chemistry concepts at the atomic and molecular level and to link this understanding to a familiar everyday context.

In the four-hour *Tires* unit, students engage in a wide variety of activities that elicit their everyday ideas, add new normative ideas about chemical bonding and physical properties, and help them distinguish among these ideas, and apply and reflect upon them. Activity 1 introduces students to the environmental strain associated with accumulating piles of unrecyclable used tires. Activity 2 illustrates the distinction between covalent bonds and intermolecular forces using the surface tension of water as an example. In Activities 3 and 4 students explore the properties, bonding, and atomic arrangements of tire rubber and plastics respectively. Students observe the properties of these substances using physical samples and videos, read about the bonding and atomic arrangements of these polymer substances, interact with molecular visualizations developed using Molecular Workbench (Pallant & Tinker, 2004), depicting the responses of these substances to changes in applied force and heat. Students also use a drawing tool to animate how electrons move within the chemical bonds, and use the evidence they gather to construct written explanations that articulate if and how tires can be recycled. In this study, students who completed Activities 1 through 4 were given the opportunity to study an optional activity on recycling ceramic materials (e.g. ionic solids).

Students use the *Idea Basket* throughout *Tires* to keep track of ideas they think are relevant to recycling tires. At the end of Activities 3 and 4, students use the *Explanation Builder* to select and sort their ideas in order to respond to the inquiry questions "Are tires recyclable?" and "Can we recycle tires like plastic?" The *Explanation Builder* first guides students to organize their ideas according to whether they support a YES or NO answer to the question (Tables 2-4). Students then construct an explanation in response to the questions based on their organized evidence. These inquiry questions compel students to integrate evidence at both the observable level (physical properties of substances or recycling methods) and the molecular level (atomic arrangements and chemical bonding). Sophisticated explanations distinguish the observable characteristics of tire rubber and plastic based on their molecular characteristics. *Tires* thus goes beyond typical classroom exercises that require only textbook definitions by engaging students in making functional and evidence-based distinctions between molecular concepts such as covalent bonds and intermolecular attractions.

Methods

Participants

Chemistry students (N=164) in 10 classes with two teachers studied *Tires* at a public high school in the western United States. Both teachers had at least five years of teaching experience and had previously used WISE in their classrooms. The school has a diverse student population with 66% underrepresented ethnic minorities and 62% eligible for a reduced-price lunch. Students worked in dyads on the *Tires* unit. A total of 82 workgroups studied the unit for 4 days.

Data sources and scoring

Idea Basket contents. We analyzed the contents of students' *Idea Baskets* at the end of Activities 3 and 4, the points where students used the *Explanation Builder* to organize ideas in response to the inquiry prompts. We scored the number of ideas (entries) in the *Basket* and recorded the type of step where each idea was generated (e.g. video, text, prompt, etc.). To link the conceptual content of students' ideas to their explanations, we identified eight *inquiry concepts* about tire rubber and plastics that are critical to answering the inquiry questions about recycling tires. We coded each idea for the presence of these concepts. Four of these concepts represent *observable* phenomena (e.g. physical properties or recycling methods): (1) tire rubber is strong or resistant to melting, (2) plastics are weak or easily melted, (3) tires can be reused or repurposed rather than melted down, and (4) plastics are recycled by melting. The other four concepts represent *molecular* phenomena (e.g. atomic arrangements or chemical bonding): (5) tire rubber has cross-linking bonds that connect polymer chains, (6) plastics lack cross-linking bonds between polymer chains, (7) covalent bonds (such as between tire rubber molecules) are strong, and (8) intermolecular attractions (such as between plastic molecules) are weak.

Explanation Builder organization. We evaluated how students organized their ideas using the *Explanation Builder* in Activities 3 and 4. We scored the placement of ideas in the organizing space in two ways. First, to capture whether students found their ideas relevant to the inquiry question, we computed the number of the eight inquiry concepts students placed in the organizing space. Second, we computed the number of these inquiry concepts that were *validly organized* (e.g. in a way that would support a valid explanation).

We judged whether inquiry concepts were validly organized according to whether they supported one of two scientific views. The first view emphasizes the difficulty of recycling tires by melting because of the presence of covalent cross-links. In this case, we judged concepts appearing in the "NO" region of the organizing space to be validly organized. The second view emphasizes the possibility for tires to be recycled either by reuse or by selectively breaking covalent cross-links (a currently researched process known as devulcanization). In this case, we judged concepts 2, 4, 5, 6, 7, and 8 to be validly organized if they appeared in the "YES" region of the organizing space and if students also mentioned the possibility of breaking cross-links. We judged concept 3 to be validly organized on either side of the organizing space in Activity 3 because of the distinction some students made between recycling and reuse. Occasionally students placed an idea on the line dividing the two sides of the organizing space. We coded these as if they had been placed on both sides.

Embedded inquiry explanations. We scored students' inquiry explanations in Activities 3 and 4 in two ways. First, to determine *completeness* we determined whether students used the organized inquiry concepts in their explanations by coding each explanation for the presence of each inquiry concept. Second, we used a Knowledge Integration rubric to score the *coherence* of each explanation from 1 to 5. Previous research shows Knowledge Integration rubrics, which reward valid conceptual connections between scientific concepts, to successfully distinguish levels of conceptual sophistication in scientific explanations (Liu, Lee, Hofstetter, & Linn, 2008). The rubric rewards connections between valid statements about physical properties, the strength of bonds or intermolecular attractions, and recycling methods. The number of inquiry concepts present in each explanation and the coherence score were highly consistent ($r = 0.76, p \leq .001$).

Pretests and posttests. Though our analysis focuses on students' use of the *Idea Manager* and their explanations, we also captured students' broad understanding of atomic structure using two pretest/posttest transfer items. The items asked students to sketch the arrangement of atoms in a polymer and an ionic substance. They were transfer items in that students did not sketch atomic arrangements during the *Tires* unit, nor did most students study the optional activity on ceramics. We scored these sketches from 1 to 5 based on whether they represented the multitude of the atoms and their bonding arrangements. Students in one class took an alternate assessment as part of a different research study instead of the *Tires* transfer items. Some students did not take the pretest or posttest because of absence.

Analysis

To illustrate the paths students' ideas took during inquiry, we traced the inquiry concepts from students' *Baskets* to the *Explanation Builder* to their eventual articulation in an explanation. In our first analysis we merged the data from Activities 3 and 4 and divided students' explanations into three tiers of coherence. Scores of 4 or 5 comprised the high coherence group (N = 24), scores of 3 comprised the moderate coherence group (N = 54), and scores of 1 or 2 comprised the low coherence group (N = 43). We examined differences in students' ideas and in their use of the *Explanation Builder* preceding explanations of varying degrees of coherence.

To clarify these findings, we used multiple linear regression to model the quality of students' explanations for each activity. We used characteristics of the *Basket* ideas and organization choices in the *Explanation Builder* to model the coherence of students' explanations. We used as predictors for the regression model (1) the total number of *Basket* ideas students had generated to that point in the unit, (2) the number of validly organized inquiry concepts, (3) the number of invalidly organized inquiry concepts, and (4) the number of unorganized inquiry concepts. We included the total number of *Basket* ideas in the model to control for the effort students made toward populating their *Baskets*. We omitted students who did not complete an explanation from the model.

Results

Fidelity of enactment and knowledge transfer

A researcher was present in the classroom throughout the enactment of *Tires*. Students engaged with the inquiry activities as intended, and there were no technical problems that would have interfered with data collection or students' inquiry progress. Students made significant gains from pretest to posttest on the drawing transfer items even though they did not draw molecular structures during the unit [$t(109) = 2.50$, $p = .014$)]. Gains were significant on the polymer item ($p = .018$), but not on the ionic item ($p = .17$), consistent with the focus of the unit on the distinctions between two polymer materials, tire rubber and plastic. This gain is unlikely to have resulted from taking the pretest alone (i.e. drawing ideas prior to instruction). This result suggests students were able to transfer their understanding of the multitude and arrangement of atoms in polymer materials from interacting with the molecular visualizations to generating static representations with the drawing tool.

Basket characteristics

Students' *Basket* ideas varied greatly in their content and complexity. In total, students generated 454 unique ideas. Of these, 214 contained at least one of the eight coded inquiry concepts, and 78 contained at least two inquiry concepts. Of these ideas, 119 contained inquiry concepts coded as observable, while 107 contained inquiry concepts coded as molecular (a few contained both observable and molecular concepts). By the end of Activity 4, students' *Baskets* contained an average of 5.99 ideas (SD = 2.99).

Although students could submit ideas to the *Basket* at any point in the unit, students added most of their ideas during three types of steps. Students submitted 24% of their ideas while viewing text-based evidence pages, 13% of their ideas while using the *Explanation Builder*, and 56% of their ideas after being prompted to submit ideas. The remaining 7% of ideas were added during other types of steps such as reflection prompts, drawing steps, videos of observable properties, or steps containing molecular visualizations.

To examine the extent to which students' *Basket* ideas were self-generated (rather than copied as text directly from the source), we coded ideas as verbatim if the entire text of the idea was taken directly from a text-based evidence page. Only 65 of the 454 ideas (submitted by 14 of the 82 student groups) were coded as verbatim, illustrating that the vast majority of students generated ideas themselves.

Tracking inquiry concepts from *Baskets* to explanations

We illustrate the paths inquiry concepts took from the *Idea Basket* to the *Explanation Builder* and ultimately to their explanations. We compared the frequency with which the eight inquiry concepts were present in students' *Baskets*, selected for organization in the *Explanation Builder*, organized validly in the explanation space, and included in inquiry explanations for high, moderate, and low levels of explanation coherence. Figure 1 presents this comparison separately for observable and molecular inquiry concepts.

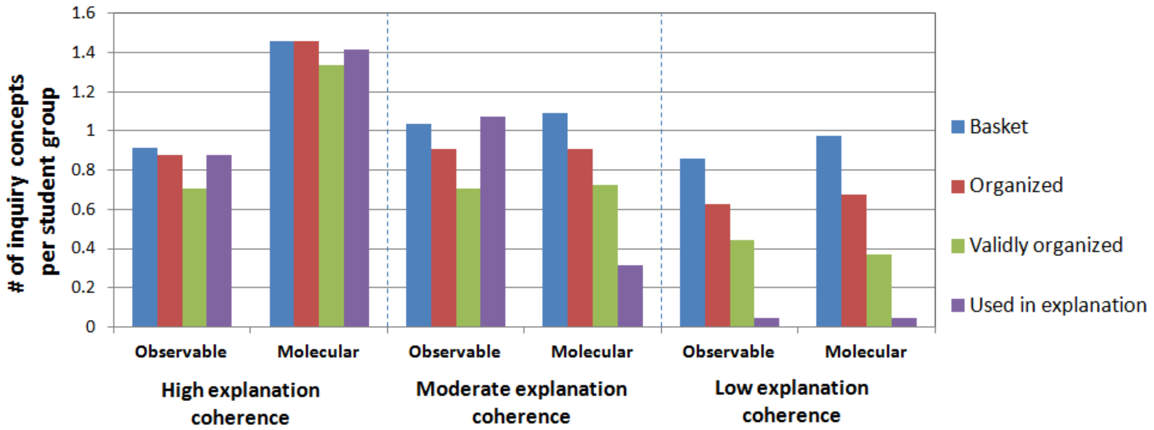


Figure 2. Frequency of observable and molecular inquiry concepts present in *Idea Baskets*, selected for organization, organized validly in the explanation space, and incorporated in inquiry explanations.

Highly coherent explainers added a relatively large number of molecular inquiry concepts to the *Basket*, organized them validly, and incorporated them coherently into explanations. Moderately coherent explainers generated nearly as many total inquiry concepts as highly coherent explainers ($t = 0.71$, $p = .48$), but validly organized only half as many molecular concepts as the highly coherent explainers ($t = 2.43$, $p = .02$) and incorporated less than one fourth as many molecular concepts into explanations ($t = 5.94$, $p \leq .001$). Overall, moderately coherent explainers relied primarily on observable concepts to support explanations and failed to incorporate molecular concepts into explanations, even when they recognized these concepts as relevant to the inquiry question. Incoherent explainers added nearly as many total inquiry concepts to the basket as highly coherent explainers ($t = 1.48$, $p = .14$) but validly organized concepts at a rate about equal to chance. Moreover, they seldom used any inquiry concepts (observable or molecular) to support explanations.

Our regression models revealed that the number of validly organized inquiry concepts was a strong and significantly positive predictor of explanation coherence (Table 1). The number of inquiry concepts left unorganized was a strong and significantly negative predictor for the Activity 4 explanations. The remaining variables did not significantly predict explanation coherence. A linear combination of the inquiry concept predictors from both activities (weighted using the number of observations) showed that the total number of *Basket* inquiry concepts also did not significantly predict explanation coherence ($p = .80$).

Table 1. Multiple linear regression models predicting explanation coherence

Learning outcome	Predictor	*B*	*SE B*	β
Activity 3: "Are tires recyclable?" (N = 74)	Total *Basket* ideas	.01	.05	.03
	Validly organized inquiry concepts	**.38**	**.19**	**.41***
	Invalidly organized inquiry concepts	-.31	.31	-.13
	Unorganized inquiry concepts	-.06	.22	-.06
Activity 4: "Can we recycle tires like plastic?" (N = 47)	Total *Basket* ideas	.07	.05	.26
	Validly organized inquiry concepts	**.50**	**.15**	**.81*****
	Invalidly organized inquiry concepts	.25	.16	.29
	Unorganized inquiry concepts	**-.35**	**.16**	**-.60***

* $p \leq .05$; *** $p \leq .001$

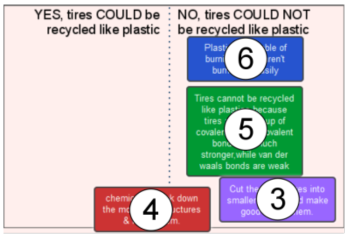
The multiple regression analysis highlights the importance of distinguishing and sorting ideas generated during the inquiry investigation. Neither the total number of *Basket* ideas nor the total number of inquiry concepts predicted explanation coherence. Accumulating ideas, even conceptually relevant ideas, is not sufficient for generating coherent explanations. Only when students used the *Explanation Builder* to validly distinguish among the key inquiry concepts did they proceed to construct coherent explanations. The higher regression coefficients in the Activity 4 model compared to the Activity 3 model likely reflect the additional opportunities students had to refine their understanding by distinguishing tire rubber from plastics in Activity 4.

Students' inquiry progress toward explanations: Three cases

To illustrate how students used the *Idea Basket* and the *Explanation Builder* leading up to their Activity 4 inquiry explanation, we describe three cases. We contrast progress toward a highly coherent explanation (Table 2), a moderately coherent explanation (Table 3), and an incoherent explanation (Table 4).

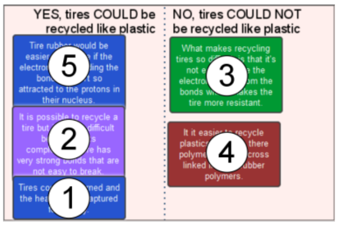
Highly coherent case. These students submitted two general ideas during the introductory activity, before *Tires* introduces specific chemistry concepts. Starting with Activity 3, they added sophisticated ideas that directly address recycling methods (Ideas 3 and 4), chemical bonding (Idea 5), and distinguishing the properties of tire rubber and plastic (Idea 6). In the *Explanation Builder*, they selected only the four specific ideas as relevant to the question and organized them appropriately. The placement of Idea 4 in the center suggests an awareness of devulcanization (though the students might simply have run out of room on the right side). The explanation that follows clearly distinguishes tire rubber from plastic on a molecular basis and, other than mistaking melting for "burning," connects the nature of the chemical bonds to observable properties.

Table 2. *Idea Basket* contents, organization space, and a highly coherent Activity 4 inquiry explanation.

#	Idea text	Organization	Explanation
1	unused tires collect standing water, creating a breeding gound for mosquitos and rodents, which can cause disease.		"No . Tires cannot be recycled like plastic because they contain a stronger bond, which is covalent. Plastic contains weak van der waals forces and therefore it is much easier to breakdown, it can easily be burned and made into other materials."
2	very hard to recycle tires		
3	Cut the rubber tires into smaller pieces and make good use of them.		
4	chemically break down the molecular structures & reuse them.		
5	Tires cannot be recycled like plastics because tires are made up of covalent bonds.Covalent bonds are much stronger,while van der waals bonds are weak		
6	Plastic is capable of burning , tires aren't burned so easily		

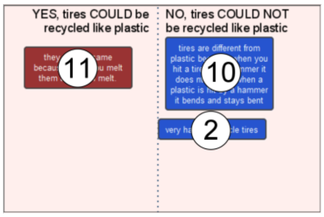
Moderately coherent case. Like the previous student group, these students added a general idea early in the project, then added several specific ideas at the sub-microscopic level during Activities 3 and 4. Ideas 3 and 5 reflect an incomplete understanding of the role of electrons in chemical bonding, while Ideas 2 and 4 are sophisticated ideas that are highly relevant to the inquiry question. Rather than selecting the most relevant ideas for organization, these students chose to organize all their ideas in an apparently arbitrary manner, as there is no clear connection between the content of the ideas and how they are organized. The explanation that follows refers only vaguely to the complexity of the bonds and omits the specific connections between bonding concepts and recycling that are present in Ideas 2 and 4. The haphazard organization and vague explanation suggest that these students had only a superficial understanding of the bonding concepts they submitted to their *Basket*.

Table 3. *Idea Basket* contents, organization space, and a moderately coherent Activity 4 inquiry explanation.

#	Idea text	Organization	Explanation
1	Tires could be burned and the heat can be captured for energy.		"We cannot recycle tire rubber like we recycle plastic because the structure of bonds and polymers in tire rubber is much more complex than plastic."
2	It is possible to recycle a tire but it is very difficult because of its complexity. A tire has very strong bonds that are not easy to break.		
3	What makes recycling tires so difficult is that it's not easy to take the electrons away from the bonds which makes the tire more resistant.		
4	It it easier to recycle plastics because there polymers are not cross linked like tire rubber polymers.		
5	Tire rubber would be easier to recycle if the electrons surrounding the bonds weren't so attracted to the protons in their nucleus.		

Incoherent case. Like the previous two student groups, these students began by adding general ideas to the *Basket*. In Activity 3, these students added seven specific ideas (Ideas 3-9) about the atomic arrangement and bonding of tire rubber. These ideas are, for the most part, copied directly from pages in the unit. In Activity 4, these students neglected to add corresponding molecular ideas about plastic, instead adding only vague or non-normative observations in Ideas 10 and 11. Given the opportunity to sort their ideas using the *Explanation Builder*, these students ignored their molecular ideas and organized only their vague observations. Thus, these students added many relevant ideas but failed to support their explanation with this evidence about chemical bonding or observable properties. Overall, they neglected to distinguish between tires and plastics at any level.

Table 4. *Idea Basket* contents, organization space, and an incoherent Activity 4 inquiry explanation.

#	Idea text	Organization	Explanation
1	unused tires collect standing water, creating a breeding gound for mosquitos and rodents, which can cause disease.		"We think that tires cannot be recycled like plastics because they are made out of nonrenewable resources and they are very hard and expensive substances. It requires high level of chemical breakdowns."
2	very hard to recycle tires		
…	…		
7	Polymer chains in natural rubber are held together loosely by VAN DER WAALS forces.		
8	Natural rubber is strengthened using a process called vulcanization.		
9	Vulcanization uses sulfur atoms to cross-link polymer chains side-to-side with more COVALENT BONDS.		
10	tires are different from plastic because when you hit a tire with ahammer it does nthing but when a plastic is hit by a hammer it bends and stays bent		
11	they are the same because when you melt them they both melt.		

Discussion

The *Idea Manager* helps students collect, organize, and distinguish their ideas and allows researchers to observe how chemistry students grapple with molecular concepts to explain everyday science. Our findings show that most students add some relevant ideas while studying *Tires*. Students' use of the *Explanation Builder* revealed that having relevant ideas did not ensure that they would generate coherent explanations. Thus, adding relevant ideas (often the main goal of typical science instruction) is not sufficient to ensure that students can use the ideas productively—instruction must provide students with opportunities to distinguish and sort their ideas. Indeed, many students generated incoherent explanations despite having identified a plethora of ideas relevant to the investigation. This study thus provides evidence to support the Knowledge Integration perspective, which describes learning as the process of connecting, distinguishing, sorting, and refining ideas rather than merely the accumulation of normative ideas. Most students in our study submitted *Basket* ideas that would have been appropriate answers to typical science assessments, but the total number of ideas was not a significant predictor of explanation coherence.

Our analysis indicates that students need guidance to integrate their ideas into generative explanations. These findings resonate with our previous studies of a physics inquiry unit where students conducted virtual experiments to test their ideas about car collisions (McElhaney & Linn, 2011). In those studies, the validity of students' experimental designs more strongly predicted students' learning outcomes than the number of experimental trials they conducted. Just as valid experimental designs illustrate meaningful distinctions between relevant concepts, the valid organizing of chemistry ideas in the *Explanation Builder* illustrates the conceptual distinctions that are necessary to construct coherent explanations. In both studies, the quantity of evidence students produced was not sufficient—they also needed guidance to organize and distinguish ideas.

Our findings also suggest that, consistent with previous research (e.g. Ben-Zvi, Eylon, & Silberstein, 1986; Kozma, 2003), students had particular difficulty using molecular concepts to support their explanations. The detailed accounts of learning provided by the *Idea Manager* suggest curriculum revisions to *Tires* that could help students better incorporate molecular views into their understanding. We designed the molecular visualizations to illustrate the relationship between physical properties and the molecular structure of substances. Our data logs indicate that less than one percent of students' *Basket* ideas were generated while interacting with a molecular visualization, compared to 24% that were submitted while reading text-based descriptions of molecular concepts. Students' molecular ideas might have been more productive had they been generated as observations of the visualizations rather than as summaries of text-based evidence. In a recent study on a WISE unit about the seasons, students submitted about 25% of their *Basket* ideas while interacting with dynamic visualizations (Matuk et al., 2012). The *Seasons* unit contains relatively little text-based evidence and encourages students to generate ideas while exploring the visualizations. The success of this unit suggests that a similar design approach with *Tires* might help students generate productive, molecular ideas that emerge from their understanding of the physical properties of substances.

Conclusions, Implications, and Next Steps

This paper illustrates how new technologies can guide students inquiry learning and help researchers closely examine the progress of students' learning during inquiry investigations. Logs of students' use of the *Idea*

Manager reveal the varied inquiry trajectories students follow. *Tires* helped some students achieve sophisticated insights about the chemistry of recycling. Other students accumulated productive ideas but were unable to integrate these ideas to reach deeper insights. These rich sources of data will be crucial to understanding the sequence of learning events that lead to students' meaningful understanding of complex science. Furthermore, these data can inform curricular revisions that strengthen connections between disciplinary concepts and everyday science. Our subsequent studies will explore the causal relationships between students' use of the *Idea Manager* and their learning outcomes. We will also investigate how inquiry scaffolding can encourage students to add more productive ideas and fewer inert ideas to their *Baskets*, as well as guide students to distinguish ideas in ways that promote more coherent scientific understanding.

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