

# OPEN-SOURCE ONLINE SCIENCE INQUIRY MATERIALS: BUILDING A COMMUNITY<sup>1</sup>

MATERIAIS ONLINE DE ACESSO LIVRE PARA APOIO A FORMAÇÃO DO PENSAMENTO  
CIENTÍFICO

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## RESUMO

Neste artigo buscamos elucidar nossa experiência na condução do TELS (*Technology-Enhanced Learning in Science*), que busca promover a aprendizagem do pensamento científico (*inquiry learning*) em estudantes a partir de 10 anos até o nível universitário. O TELS é apoiado por um ambiente acessível via Internet chamado WISE (*Web-based Inquiry Science Environment*), o qual possui um acervo de atividades de aprendizagem em diversos idiomas. Detalhamos os fundamentos que nortearam a construção do ambiente e exemplificamos algumas unidades de estudo que consideramos representativas ligadas a temas como o Clima Global, Mitose das Células e Reações químicas que estão disponíveis no WISE. No artigo detalhamos o conceito de integração de conhecimentos que julgamos ser um elemento chave para o desenvolvimento do pensamento científico. Atualmente o programa TELS atende a centenas de professores, pesquisadores e criadores de conteúdo, bem como dezenas de milhares de estudantes.

## INTRODUCTION

We need internationally available and effective curricular materials on science inquiry and instructional strategies. Instruction on enquiry is especially important for preparing students to deal with the complex scientific issues we face today, such as the formation of policies for sustainable energy, making sensible health-related decisions, and ensuring food safety. We report on a successful,

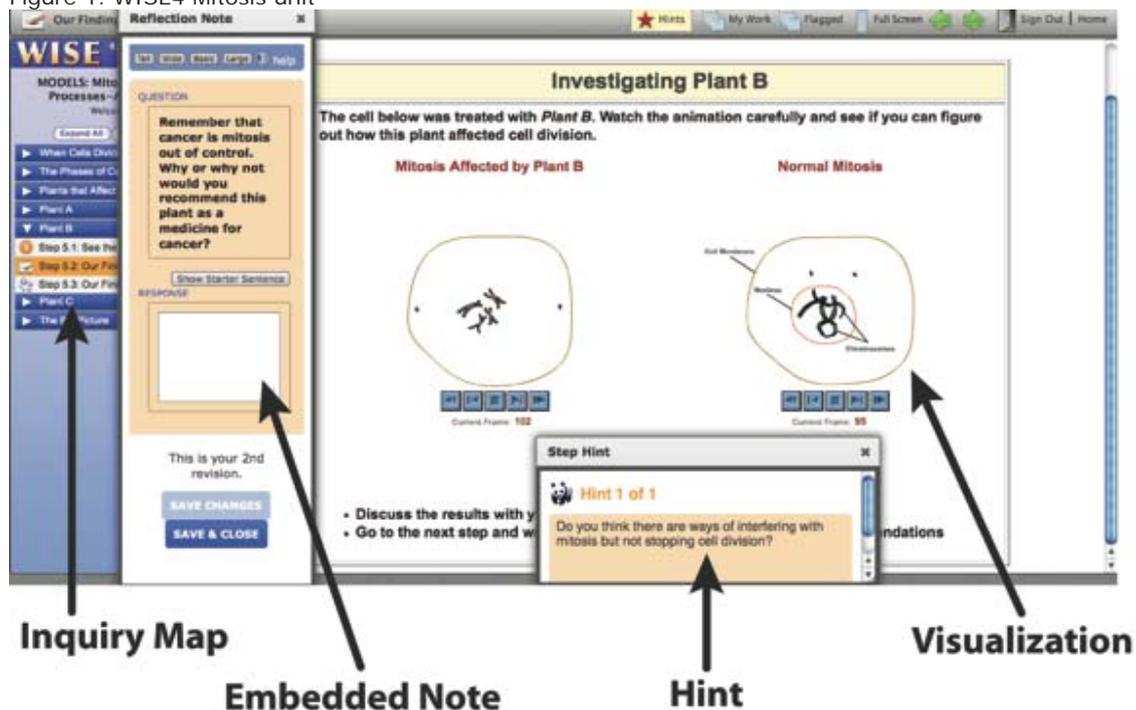
open source learning environment that supports the authorization and customization of materials for science inquiry.

Technology-Enhanced Learning in Science (TELS) National Science Foundation (NSF) is funded center for learning and teaching created an *educational accelerator* to promote inquiry learning. The educational accelerator includes the Web-based Inquiry Science Environment (WISE), a set of curricular units implemented in WISE, and a synthesis of research on science inquiry called knowledge integration (Linn & Eylon, 2011).

WISE can support the international community in the cumulative development of science inquiry materials. It is open source, free, and available in multiple languages. The WISE library has units for courses in life, physical, and earth science as well as biology, chemistry, physics, and environmental science for students from age 10 through to college age. WISE has an authoring system that makes it easy to customize units, translate units into new languages, and author new units in any language.

WISE projects engage students in collaborative activities with visualizations such as investigating hypotheses, designing solutions to problems, critiquing scientific claims, and building scientific models. Students are guided by an inquiry map (see Figure 1). Assessments are embedded throughout the WISE projects to help students and teachers monitor student understanding and progress as students interact with the visualizations. The embedded assessments ask students to make predictions about the visualizations, sort out evidence, and link ideas together to explain their thinking. Students can obtain hints to help them complete tasks.

Figure 1. WISE4 Mitosis unit



## NATURE OF INQUIRY

Many theorists and instructional designers have demonstrated that students become engaged in science learning when the problems they study are relevant to their lives. Students often argue that the abstract depiction of scientific phenomena in science classes will not enable them to live better lives. They do not see how Newtonian laws of motion can help them improve their baseball skills. They cannot connect the stages of mitosis to the treatment of cancer. They find the laws of thermodynamics useless for finding ways to keep warm on a cold day. Science inquiry instruction

focuses on problems that are relevant to students' lives and engages them in exploring solutions as well as strengthening the skills necessary to solve the next problem they encounter.

By focusing on problems that are personally relevant to them, science instruction draws on the ideas and strategies that students develop in their lives and help them reformulate, reconceive, and refine these ideas. Students develop solutions to problems they encounter such as keeping food safe for a picnic, throwing a ball further, or making sense of an earthquake. They look for explanations to dilemmas such as keeping warm while swimming or avoiding the flu.

Inquiry learning involves combining investigative strategies and disciplinary knowledge to explore compelling problems. Students cannot make progress in understanding why it is difficult to recycle tires without understanding the types of bonds in plastics, ceramics, and tires. They cannot conduct investigations of airbag safety without recognizing the variables that are important – and the threshold effects that contribute to the solution (McElhane & Linn, 2012). But neither can students design investigations or construct an argument without using scientific methods. Effective science inquiry projects engage students in combining investigative strategies and disciplinary knowledge. A wide range of investigative strategies are relevant to inquiry learning. Students need to construct comparison tests using valid techniques. They need to evaluate their own progress and look for gaps in their knowledge. They need to collaborate with peers and gather information from experts. Effective inquiry science projects help students develop a robust set of inquiry strategies.

When science instruction connects to questions and ideas students have developed, they have the opportunity to refine their ideas and their investigative strategies. Effective inquiry instruction takes advantage of research demonstrating the value of guiding students to compare and contrast ideas that they develop themselves as well as new ideas introduced in classes (Quintana et al., 2004). It identifies ways that such guidance can ensure students learn to select promising ideas and use their developing investigative strategies and disciplinary knowledge to address problems in new settings throughout their lives.

Thus, inquiry involves investigating a compelling or driving question such as:

- How do greenhouse gases accumulate?
- What is a good design for an energy-efficient house?
- Why are tires difficult to recycle?
- When are airbags dangerous?
- Can you design a cancer drug to influence mitosis?
- What causes the seasons?
- How does the sun provide food for animals?

Inquiry instruction engages students in generating their own ideas about the driving question. It motivates students to add additional perspectives from doing experiments, observing phenomena, consulting experts, and collaborating with peers. It guides students to weigh alternatives, consider arguments for and against possible solutions, critique claims, debate their peers, and gather additional evidence to resolve discrepancies. It also helps students consolidate their ideas by reflecting on all the diverse perspectives and proposing a coherent solution, recommendation, or plan for further investigation.

## PERSPECTIVE ON LEARNING AND INSTRUCTION

Extensive documentation of the diverse, creative, and unique ideas that students formulate has led researchers to argue for a constructive process of knowledge generation and growth of understanding. Many researchers have focused on the diversity and nature of student's ideas. These ideas have been referred to as "misconceptions," "alternative conceptions," "beliefs," "intuitive ideas," "p-prims" and "constructed ideas." To support cumulative, coherent understanding, instructional perspectives need to account for the emergence of these views, as well as their role in learning. A large body of evidence has led researchers to argue that students construct multiple, contradictory,

and fragmented ideas that stem from their interactions with the material and social world (e.g., Bransford, Brown, & Cocking, 1999; diSessa, 1988; Duit, 1999). These researchers have shown that the ideas students generate arise from observations, analogies with related events, cultural practices, or colloquial uses of language. They have demonstrated that when students encounter classroom tasks that ask for abstract de-contextualized explanations, they often respond quite differently from when asked to explain an observed phenomenon (e.g., Clark, 2006; Clark & Linn, in press). Students' methods for grappling with new observations strengthen the view that students engage in a creative process of trying to make sense of their world (Hatano & Inagaki, 2003).

Recently Marcia Linn and BatSheva Eylon reviewed the literature on science inquiry and synthesized the findings (Linn & Eylon, 2011). They reviewed research on textbooks, lectures, hands-on experiments, modeling and simulation, collaborative learning, and professional development. They identified a pattern that was associated with successful inquiry instruction in all of these areas, referred to as the knowledge integration pattern. The pattern has four main processes: Eliciting students' ideas; adding new ideas; engaging students in distinguishing ideas; and guiding students to reflect and rearticulate their ideas.

*Elicit student ideas* using brainstorms, predictions, and pretests to characterize the rich repertoire of ideas students have about any inquiry question. Many studies show instructional benefits of asking students to predict outcomes or explain their own ideas before adding new ideas (Gunstone & Champagne, 1990; Minstrell & diSessa, 1988). Eliciting ideas focuses learners on the strategies they have used in the past to make sense of a science topic. When students make a prediction, they use reasoning processes such as linking ideas, creating arguments, or articulating experiences that are useful for making sense of scientific problems. These strategies can be refined with appropriate instruction. Eliciting ideas also gives teachers a better idea about the views and reasoning strategies of their students. Thus, by eliciting ideas, instruction builds on the cultural and intellectual diversity of learners, ensures that students consider their own ideas when evaluating new ideas, and enables teachers to tailor their instruction to their students.

*Design and add new ideas* to help students evaluate their own ideas. Instruction generally includes adding new, scientifically normative ideas. Often these ideas are inaccessible to students because they are too abstract, too complex, or require knowledge that the students lack. Thus, curriculum designers need to create ways to introduce new ideas so that they are accessible to learners. Designing effective ways to introduce new ideas is challenging. We have found that introducing ideas as "pivotal cases" where there is a controlled experiment that highlights a key distinction, is extremely valuable (Linn & Eylon, 2011). Designers often take advantage of classroom experiments, virtual experiments, or visualizations that illustrate unseen processes or large-scale phenomena to make science accessible (e.g., for electricity, Shen & Linn, in press). Ideas are often more accessible when connected to a personally-relevant context.

Engaging students in *distinguishing ideas* by generating explanations, making drawings of their ideas, critiquing experiments of others, debating alternatives, or using evidence to negotiate with peers who hold different ideas. Instruction often neglects the process of distinguishing between ideas. Extensive research shows that students are likely to add new ideas—at least while they are in science class but do not abandon the ideas they brought to science class (e.g., Gilbert & Boulter, 2000; Krajcik, Blumenfeld, Marx, Bass, Fredricks, & Soloway, 1998). Reiser and his collaborators illustrate the value of instruction that structures and problematizes new ideas so that students can distinguish them from existing ideas (Reiser, 2004; Sandoval, 2003; Sandoval & Reiser, 2004).

Guide students to *reflect and rearticulate* their ideas in summative reports, persuasive letters to policy makers, journal entries, or poster presentations. Distinguishing among ideas is not sufficient to reach new insights and can even reinforce the idea that there are many explanations for a scientific phenomena. Effective inquiry activities engage students in a culminating activity that involves rearticulating and integrating their ideas. Research shows that reflection is a powerful instructional activity (Collins & Brown, 1988; Davis, 2004).

The four processes work together to enable students to integrate ideas. Together the processes contribute to the ability of everyone to become a lifelong science learner.

The knowledge integration framework takes advantage of research demonstrating the value of guiding students to engage in inquiry, so they learn to compare and contrast ideas that they

have developed themselves, as well as new ideas introduced in classes. It identifies ways that such guidance can ensure that students learn to select promising ideas and use this process in new settings throughout their lives.

### EXAMPLE UNITS

WISE projects target topic areas that are aligned with state and national science standards, that research suggests are difficult to teach, and that lend themselves to use of scientific visualizations. WISE uses visualizations to illustrate ideas that cannot be observed directly, such as molecular phenomena (e.g. chemical reactions), phenomena that occur too quickly to observe (like airbag deployment), or phenomena that are too vast to observe (like planetary motion). Each WISE project typically takes 5 to 7 50-minutes of class time to complete.

### GLOBAL CLIMATE

The WISE Global Climate unit engages students in exploring how greenhouse gases might cause global warming. Designers include Keisha Varma (Varma & Linn, in press), Vanessa Svihla (Svihla & Linn, 2011), Tammie Visintainer (Visintainer et al., 2011), Elissa Sato (Sato & Svihla, 2012), Sepehr Vakil, and others. It features MySystem (Figure 2), a concept mapping tool designed by the Concord Consortium (<http://mw.concord.org>), and a NetLogo model (Figure 3) designed by Robert Tinker at the Concord Consortium. The NetLogo model allows students to vary factors that contribute to climate such as the albedo effect, atmosphere, and human activities. In the recent version of Global Climate students explore human contributions to greenhouse gas accumulation.

Figure 2. Interface of the MySystem tool

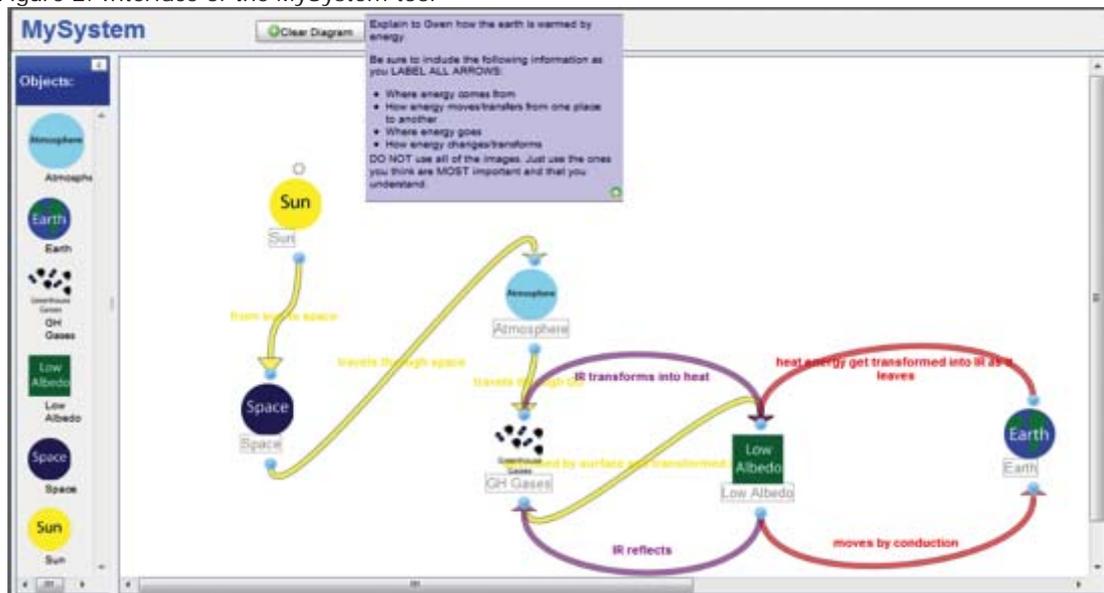
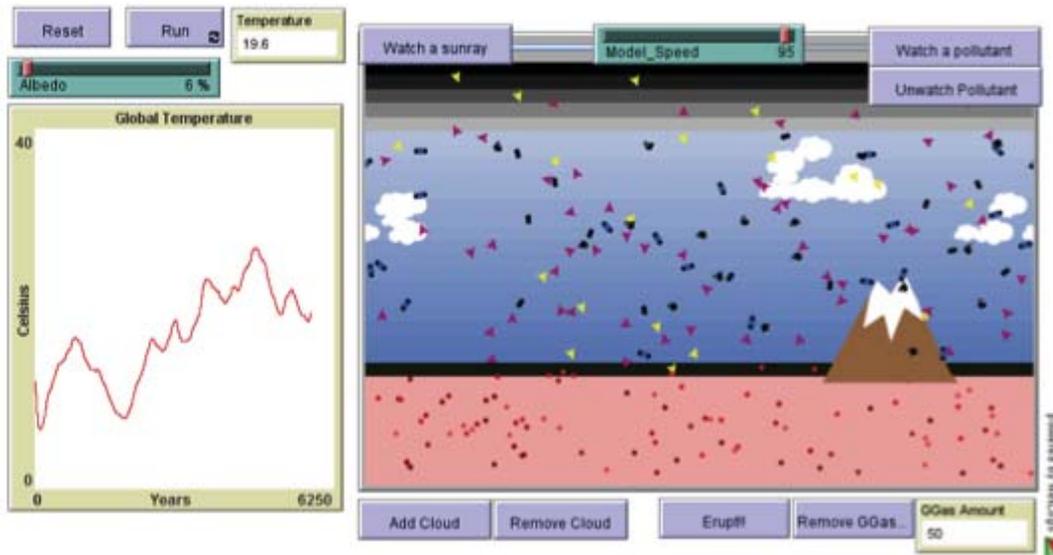


Figure 3. A NetLogo model in which students can observe how energy is transformed and interacts with greenhouse gases and other factors



*Elicit Student Ideas.* When asked to explain why or how greenhouse gases might cause global warming, students draw on school ideas and experiences to generate many links and connections. For example Svihla and Linn (2011) make the following comments:

“The sun is made out of gases, and it’s the world’s source of energy, therefore more gases make it even warmer!” This student starts with a valid idea that the sun is a source of energy and then assumes that the sun heats the earth with gases. The student then asserts that greenhouse gases add to the total amount of gases and therefore cause global warming.

“I think it would make a warmer climate because when coal burns it is warm, so it would make a warm climate.” This student is articulating a common belief that burning coal (or other things) adds heat and causes global warming.

“It will be warmer because you breathe (sic.) out carbon dioxide. It’s warm so if more carbon dioxide increases it will be warmer.” This answer introduces carbon dioxide but links it directly to increases in heat.

Many students draw on a variation of the valid idea that if you add heat to a system it will get warmer. Designing instruction to engage students in inquiry about the causes of global warming can build on this idea. Students also realize that the sun is an important part of the system but few come to science class with accurate ideas about how this system actually works.

*Design and add ideas.* To help students understand the complex relationships that contribute to global climate change, we have collaborated with Robert Tinker to create an authorable NetLogo model of climate change. We use the model to enable students to investigate the role of energy transformations in global climate processes. Students explore the transformations from solar radiation to thermal energy, from thermal energy to infrared radiation, and from infrared radiation to thermal energy. In addition, students use the model to explore how greenhouse gases can reflect infrared radiation back towards the earth. They also compare the reflective properties (albedo effect) of ice, oceans, forests, cities, and deserts to understand the effects of rising ocean levels or deforestation. They explore the role of atmosphere and the contributions of various human activities such as burning fossil fuels, eating meat rather than vegetables, and recycling.

*Distinguish ideas.* The NetLogo model introduces important ideas but does not necessarily enable students to distinguish ideas. For example, students need to be able distinguish infrared radiation from solar radiation. Infrared radiation is reflected back towards the earth by greenhouse gases, increasing the global temperature. To help students interpret the visualization we added a challenge question (Figure 4). This question ensured that students made sense of the details of the visualization.

In earlier versions of the unit we used prompts to focus students' attention on the path of infrared radiation. This was only moderately successful. To strengthen the instruction, we have designed a pivotal case where students could follow a sunray and compare alternative energy transformations undergone by a sunray (Figure 5). Students can track a sunray where solar radiation is transformed into thermal energy and compare it to a sunray where solar radiation was reflected. Inquiry prompts asked students to explain how the transformations contributed to changes in global temperature. This pivotal case highlighted the transformation and reflection of solar radiation and helped students construct narratives to explain the role of infrared radiation in climate change.

Figure 4. A challenge question prompting students to focus on salient information in the visualization

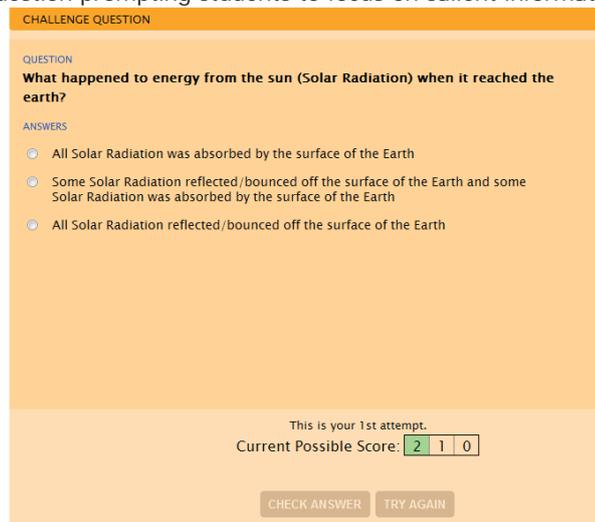
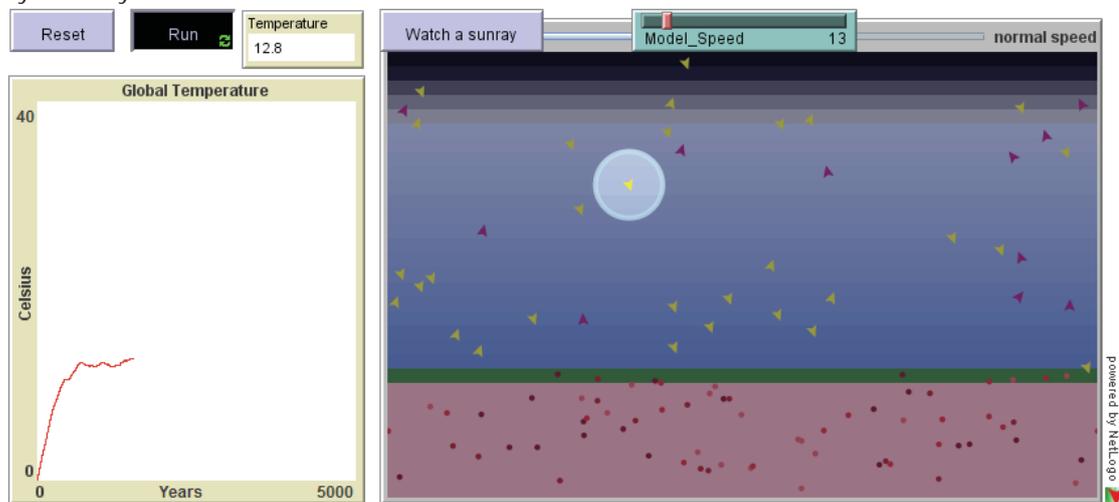


Figure 5. A NetLogo model allowing students to compare alternative energy transformations undergone by a sunray



*Reflect and rearticulate ideas.* Students conduct a series of investigations with NetLogo models that allow them to vary individual factors, clarify energy transfer and transformation, and observe the effects of human activities on global temperature. To sort out their findings in a coherent account of global climate, the unit uses MySystem and Energy Stories. Students used MySystem to track energy transfer and transformation in global climate change. MySystem allows students to represent a sequence of energy transfers and transformations. Energy Stories are narrative accounts of complex scientific phenomena. In Global Climate, students were asked to “Write a story to explain how the earth is warmed by energy.”

*Results.* To measure students' progress, we use a variety of outcome measures including MySystem, Energy Stories, and short essays. All of these tasks are scored using the knowledge integration rubric

(See Table 1). Overall, across multiple versions of the Global Climate project, students have made significant gains from pretest to posttest on MySystem, Energy Stories, and short essays (Varma & Linn, in press; Svihla & Linn, 2011; Visintainer et al., 2011; Sato & Svihla, 2012). In addition, refinements to the instruction have led to improved student outcomes (Svihla & Linn, 2011).

## MITOSIS

In the Mitosis project, students meet and work with Dr. Chavez, a plant biologist working in the South American rainforests to identify plants that can be used to treat cancer. Students compare the impacts of three plant-based medicines on mitosis and determine which one would have most potential to serve as a cancer treatment.

*Elicit student ideas.* Mitosis elicits ideas about cancer and cell division by asking students to explain how cancer works to a friend. Students predict the rate of cell division for nerve, muscle, skin, and liver cells. They also predict what would happen to body parts if cells started dividing out of control. In this unit students keep track of their ideas using the Idea Manager and use them to construct explanations in Explanation Builder (see Figure 6).

Figure 6. An Idea Manager and Explanation Builder step in the Mitosis project. Students have access to ideas they added to the idea manager during previous steps (left column) when constructing explanations (lower right)

The screenshot shows the WISE v4 interface for the 'Mitosis & Cell Processes (w/Annotator)' module. The top navigation bar includes 'Full Screen', 'My Work', 'Flagged', and 'Home / Sign Out'. The left sidebar lists steps from 2.1 to 2.11, with 'Step 2.6: Identifying phases (EB)' highlighted. The main content area features a task description: 'Scientists divide the process of cell division into phases to make it easier to talk about. But it can be hard to agree where one phase ends, and the other one begins! Give it a try now with your partner. Drag your observations onto the time line, and discuss whether they should be in one phase or another.' Below this is a table titled 'Your Ideas' with columns for 'Your Ideas' and 'Flag'. The table contains three entries: 'phase for # 2 was 153-202. We picked this phase because we could tell that the centrioles started combining with the spindle fibers', 'first phase ended when the centrioles started to separate', and 'chromosomes duplicated in 3rd phase'. To the right of the table is a timeline visualization with three blue boxes corresponding to these ideas. Below the timeline is a text input area for an explanation, with a prompt: 'How did you and your partner decide where the first phase ended?'. The explanation text reads: 'Our first phase ended just before the chromosomes attached to the spindle fibers. The chromosomes attach to spindle fibers in Metaphase, so we ended Prophase just before that happened.'

*Design and add ideas.* Students gain insight into cell division by comparing rates of cell division for different cell types. They manipulate a visualization of normal mitosis to learn about the characteristics of each of the mitosis phases. Students then investigate a visualization of mitosis when treated by each of the three plants. The plant visualizations are placed next to the visualization of normal mitosis so that students can distinguish each plant's effects.

*Distinguish ideas.* Students manipulate visualizations to compare the phases of mitosis in normal cell division, to cell division when treated by three different plant medicines (See Figure 1). Students generate an explanation for why each of the three plants would succeed or fail as a cancer treatment. An online debate then encourages students to use evidence to argue for and against each of the plants, raising issues about which phase of mitosis to target, and potential side effects. As one student remarked, "I would recommend Plant B because it affects the chromosomes directly so it stops mitosis completely. Since cancer is cells dividing out of control, stopping the division is good. But if all cells are stopped from dividing, then there would be no way to repair hurt tissue."

*Reflect and rearticulate ideas.* Students write a recommendation to Dr. Chavez for one of the three plant medicines for cancer treatment using evidence that they have gathered throughout the

project from the visualizations, evidence pages, and their online debate. Students describe how their medicine specifically affects the mitosis process and why this matters for treating cancer and the possible side effects.

*Results.* Students made significant gains from a pretest to a delayed post test on mitosis knowledge integration assessment items aligned with instruction. A longitudinal study suggests that students' learning gains improved substantially each year the teachers implemented the WISE unit, both for teachers who participated in typical and intensive professional development (Gerard, Liu, Varma, Corliss & Linn, in press). As the teachers became more proficient with the mitosis unit and the range of students' ideas as they progress through the project, they identified important places within the project to provide feedback on students' explanations and lead class discussions, to help students' sort out and integrate their ideas.

## CHEMICAL REACTIONS

WISE authors have designed several units on chemical reactions. One version combines understanding of the remainder and limiting reactions with the study of global climate (Chiu & Linn, in press). The middle school unit engages students in comparing hydrogen fuel cell cars to gasoline-powered cars (Zhang & Linn, 2011).

To form a coherent understanding of chemical reactions such as hydrogen combustion, students need to connect three representations: observable (e.g., the explosion when a balloon filled with hydrogen is ignited), symbolic (the equation  $2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$ ), and molecular (formation of chemical bonds between hydrogen and oxygen atoms). Several researchers have shown that students have difficulty making these connections (e.g., Gilbert & Treagust, 2009; Kozma, 2003).

*Elicit student ideas.* Students' conceptions of chemistry reflect their observations of everyday phenomena such as lighting campfires, making cakes, and using detergents (Clark & Linn, 2003; diSessa, 1988; Linn & Hsi, 2000). Students impute characteristics to the atomic world based on observable information. Students may believe atoms and molecules share the same properties as tangible materials, e.g., they may believe copper atoms have gravity and temperature (Ben-Zvi, Eylon & Silberstein, 1986). Some students envision chemical reactions as one-step processes through which reactants change into products, some report that atoms form one gigantic molecule at the end of a chemical reaction, and others argue that the molecules all break into individual atoms and then reconnect as products (Zhang & Linn, 2011). Thus students hold fragmented and incoherent ideas about chemical reactions. Nevertheless these ideas have value for integrating knowledge, and students can build on them to form coherent ideas. For example, students who expect molecules to break into atoms have the concept of bond breaking.

*Design and add ideas.* To help students build more coherent ideas about chemical reactions, the unit features a computational visualization of the reaction of hydrogen and oxygen designed using Molecular Workbench (Xie & Tinker, 2006). The visualization includes a pivotal case where students can compare the molecular interactions without adding a spark, and when a spark is added and water is formed (See Figure 7). The visualization shows that this is an exothermic reaction that requires the activation of energy.

Figure 7. WISE4 Chemical Reactions visualization

**Model hydrogen reaction (Part 1)**

This model shows how hydrogen and oxygen burn to form water. The equation for this reaction is:  

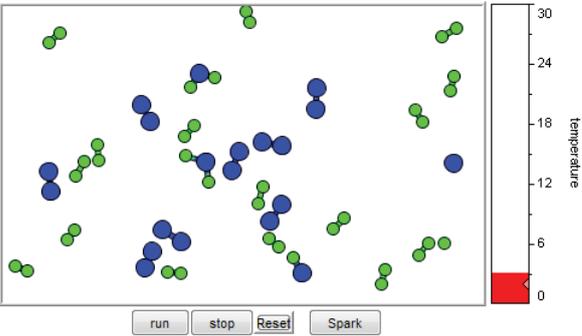
$$2\text{H}_2 + \text{O}_2 \rightarrow 2\text{H}_2\text{O}$$

**Instructions:**

1. Run the model.
2. Then press the spark button to initiate the reaction.

**Key**

- Hydrogen molecule  (H<sub>2</sub>)
- Oxygen molecule  (O<sub>2</sub>)
- Water molecule  (H<sub>2</sub>O)



**Questions to consider while running the model:**

- Does this reaction produce water molecules?
- How do the chemical bonds between hydrogen atoms change?
- How do the chemical bonds between oxygen atoms change?

*Distinguish ideas.* Research on student understanding of the visualization demonstrated that many students found it deceptively clear (Chiu & Linn, 2012; Linn, Chang, Chiu, Zhang, & McElhaney, 2010; Zhang & Linn, 2011). They watched it once and concluded that they now understood the process but when asked to explain, they had limited understanding of bond breaking and bond formation. To encourage students to distinguish the ideas in the visualization from their own ideas, investigators have added scaffolded guidance for exploration and asked students to draw the main stages of the reaction. In a comparison study, Zhang and Linn (2011) report that drawing the main stages is more effective than exploration. Examination of log files reveals that when students are asked to draw their ideas, they often go back and look at the visualization to clarify the process of chemical reactions.

*Reflect and rearticulate ideas.* To encourage students to reorganize their ideas and make links using the new ideas, students are asked to explain why hydrogen fuel cell cars are energy efficient or to write a persuasive letter to a politician explaining how excess reactions lead to global climate change.

*Results.* In many studies involving various teachers, the results show that students make progress in developing coherent understanding of chemical reactions, outperforming students studying the typical curriculum (Chiu & Linn, 2011; Linn, Lee, Tinker, Husic, & Chiu, 2006). Drawing helps students to distinguish ideas and gain coherent understanding (Zhang & Linn, 2011).

## PROFESSIONAL DEVELOPMENT FOR WISE

The same knowledge integration framework that guides the design of WISE inquiry units also characterizes effective professional development. The framework is based on extensive research, which suggests that simply adding new ideas about the target science discipline or teaching practice is not sufficient for inducing behavioral change. Teachers have a repertoire of ideas about teaching with technology, based on their observations, experiences, and preservice or professional development courses (Davis, 2006). The knowledge integration perspective emphasizes asking teachers to articulate their ideas about technology-enhanced instruction and learning, adding ideas to teachers' repertoire in ways that make the new information accessible, enabling teachers to use evidence to sort out and distinguish among these new ideas and their existing views, and encouraging teachers to engage in an ongoing process of reflecting on and integrating the ideas, which most appropriately explain the teaching and/or learning phenomena in their practice (Linn & Eylon, 2011).

*Elicit Ideas.* The repertoire of ideas that learners develop as a result of experience, observation, and instruction is central to learning a new professional practice. Teachers come to professional

development programs with a set of views about the content they teach, the capabilities of their students, learning processes, pedagogical methods, curriculum materials, technology, and inquiry. Teachers' ideas about science instruction are supported by various forms of evidence including perceived success of their teaching, their own learning experiences, students' performance on standardized and classroom tests, and feedback from students about their satisfaction using particular instructional tools (Davis, 2003; Sisk-Hilton, 2009). Effective professional development activities elicit teachers' existing ideas by asking for predictions, critiques of practices, and brainstorming of ideas. They elicit ideas about relevant science concepts and teaching practices so that these views can be inspected, analyzed, potentially contradicted, and refined. The value of supporting learners in articulating their initial ideas is apparent in numerous studies (e.g. Piaget & Inhelder, 1969; White & Gunstone, 2008). Supporting teachers in both building on and challenging these ideas is important for successful professional development.

*Add Ideas.* Successful professional development programs generally introduce new instances of and insights about technology-enhanced inquiry instruction and new disciplinary knowledge. Videotapes of classroom practice may effectively introduce new ideas (Brunvand & Fishman, 2007). Many programs also ask teachers to role-play a student using technology-enhanced curricula in order to introduce teachers to the ideas students may learn and the challenges they may encounter (Davis, 2006). Teachers themselves sometimes add ideas by collaborating with a peer to discuss lesson plans and student work (Gerard, Spitulnik, & Linn, 2010). When supporting teachers in adding new ideas, the new information is most compelling when it is tightly linked to classroom practice (Borko, 2004) and evidence of learning (Little, 2003). Adding ideas through lectures or videos without connecting them to existing ideas means that the ideas are often isolated and rapidly forgotten.

*Distinguish Ideas.* Even when ideas are connected to existing knowledge, teachers might add ideas to their repertoire but not use the ideas in their practice. Consistent with the knowledge integration framework, many studies show that teachers' new ideas about technology and inquiry science instruction do not straightforwardly replace their existing views about teaching and learning (e.g. Spillane, Reiser & Reimer, 2002). Established practices may have developed over years of teaching and are supported by a variety of evidence. For example, in technology-enhanced science education, many teachers initially believe that students will learn on their own when working with computer-based simulations (Slotta, 2004). Although this is a good goal, research suggests that this rarely occurs among students in a typical science classroom (Fishman, Marx, Best, & Tal, 2003; Tal, Krajcik & Blumenfeld, 2006).

The knowledge integration framework emphasizes helping teachers to distinguish among new and existing ideas, and to use criteria based on evidence to select the ideas that most aptly explained successful teaching practices. Technology-enhanced materials often collect continuous indicators of student progress that give teachers excellent opportunities to use evidence to distinguish their new ideas from past teaching practices, weigh alternatives, and reflect on how best to proceed. WISE embedded assessments, for example, can give teachers evidence of student thinking as they interact with visualizations. This kind of data may encourage teachers to distinguish new ideas from their intuitions. Teachers can determine when students need external scaffolding while working with visualizations to engage in inquiry processes such as question posing, data collection and synthesizing.

*Reflect and rearticulate ideas.* Teaching practices are usually well established and change gradually. Effective professional development supports teachers to use evidence to reflect on their knowledge, and integrate ideas of science content, student learning, curriculum and teaching to form a coherent instructional framework. This calls for an ongoing process of refining and broadening ideas.

Experts in the field of science teacher education emphasize helping teachers make links among their ideas to gain robust insights (Ball & Bass, 2000; Davis, 2003; Henze, Driel, & Verloop, 2008; Niess, 2005). Schulman (1986), for instance, refers to teachers' integrated knowledge about practice as pedagogical content knowledge. He frames the development of pedagogical content knowledge as an ongoing activity. For example, teachers benefit from linking their prior knowledge about how students deal with orders of magnitude to new ideas about how students reason when constructing a computer-based model of the solar system (Henze et al., 2008). Teachers need to combine ideas about their students' existing repertoire of ideas and the new ideas their students are adding from the visualizations to customize their instruction so it helps students to reflect on and distinguish their ideas. This enables teachers to scaffold students' learning progressions in technology-enhanced inquiry science (Niess, 2005).

*Results.* Programs that last for two or more years and that align with the knowledge integration framework are more successful in preparing teachers who improve student outcomes than shorter programs that are not aligned (Gerard, Varma, Corliss, & Linn, 2011). The shorter programs often lack opportunities for teachers to gather and reflect on evidence of students' learning directly related to their questions of instruction. The longer programs provide opportunities for teachers to formulate ideas about teaching with visualizations, test these ideas in the classroom, and analyze the student learning data relative to instruction. WISE creates particularly valuable opportunities for professional development as it provides each teacher with a record of their students' thinking at precise moments in the project, and the opportunity to customize the project accordingly based on their analysis of the student learning data.

## AUTHORING IN WISE

WISE authoring tools make it easy to customize units and to design new units. Any user with a teacher account can create copies of an existing project and customize them, as well as build new units from scratch. The authoring tool has a user-friendly interface that enables designers to take a flexible, modular approach (Figure 9). It provides authors content and assessment step types including MySystem, questionnaires, discussions, open response, multiple choice, drawing, peer review, animations, and graphs (see Table 2). A robust preview function and content input templates within the authoring tool lowers the barriers to entry (Figure 10).

Consistent with the emphasis on knowledge integration patterns, WISE developers are encouraged to use combinations of step types to support learners (See Table 3). Using these sequences and the knowledge integration pattern, authors can incorporate visualizations developed using external tools such as Flash, Net Logo or Molecular Workbench as well as link to rich, authentic scientific databases. The WISE authoring environment enables authors to embed the dynamic visualizations and data bases into tested inquiry instructional patterns.

Once the activities and steps are created, authors can easily rearrange and edit sequences of activities and individual steps. When a project is ready, users can choose to share their project with any other users. This gives the other user access to their project, associated documents, and any prior comments for grading within the project. This creates possibilities for teachers and designers to build on each other's work and findings.

As an open source platform, WISE is also highly adaptable. New step types can be developed as plug-ins and integrated into a select instance of WISE at any institution. A thriving community of active WISE developers worldwide currently collaborate online in a variety of feature extension projects (<https://groups.google.com/forum/?fromgroups#!forum/wise4-dev>).

Figure 8. Interface of the authoring tool

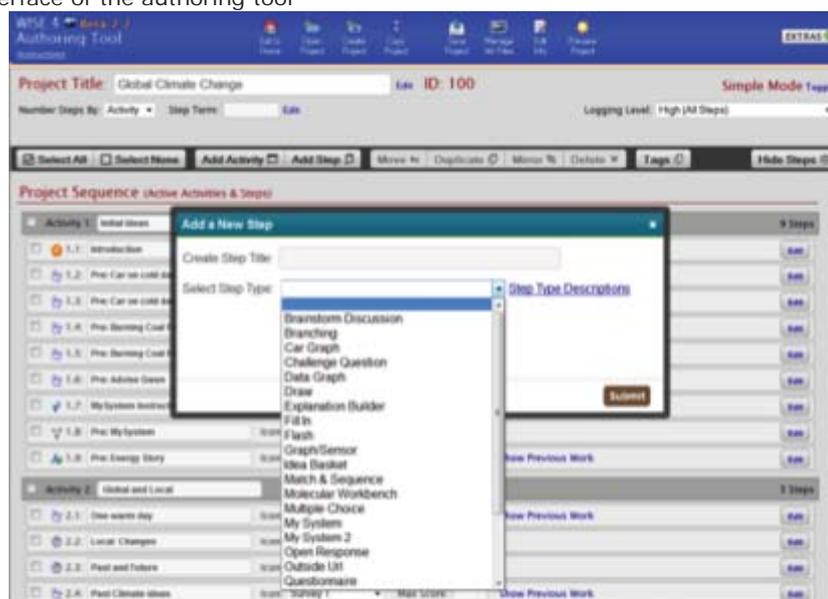


Figure 9. Preview function of the authoring tool. The left panel functions as a template, allowing the author to focus on creating the content of the step while previewing the step in the right panel



## CONCLUSIONS

WISE offers an online, open source curriculum design and delivery system as well as an opportunity for international collaboration that can contribute to the creation of a worldwide, concerted effort to strengthen inquiry instruction. WISE makes it easy for the science education community to reuse, refine, and customize innovative materials created by others and stored in the WISE library. Rather than allocating scarce resources to reinventing an inquiry activity or unit, investigators and classroom teachers can start with a tested solution and add value.

Since WISE is online Using WISE for design of experiments allows researchers to conduct rigorous investigations. WISE collects detailed records of student activities in a wide range of embedded assessments. Researchers can randomly assign students to varied conditions even in the same classroom. International collaborators can investigate the reactions of teachers in different cultural contexts to similar inquiry activities (Chang, Zhang, & Linn, 2011). Research collaborators can explore how students in varied cultural contexts respond to inquiry learning (e.g., Clark et al., 2011). Assessments designed as WISE units could be used as a measure of sustained student learning. Rather than asking students to recall details, these assessments would be able to measure students' ability to carry out an investigation and gain integrated understanding.

We invite individuals interested in improving science inquiry materials to join our community of researchers who support each other as they explore more complex questions and more powerful technologies. The TELS educational accelerator is used by hundreds of researchers and developers, thousands of teachers, and tens of thousands of students. TELS was initially funded for 5 years with a total grant of 10 million dollars to investigate how powerful scientific visualizations embedded in inquiry projects could improve science teaching and learning. Subsequent funding for Designing Coherent Science Education (Kali, Linn, & Roseman, 2008) resulted in a synthesis of the findings from TELS and the Center for Curriculum Materials in Science (CCMS). Currently the TELS community is supported by grants to the University of California, Berkeley, Concord Consortium, ETS, University of Toronto, Michigan State University, University of Georgia, Rutgers University, University of Minnesota, and Vanderbilt University. The members of the TELS community continue to collaborate. The community gathers together at retreats, workshops, and professional meetings such as the International Society of the Learning Sciences.

National and international users of WISE include K-12 teachers, university faculty and researchers, and open-source curriculum developers from across the United States and in countries including Taiwan, Brazil, Italy, Japan, and Norway. Each user is adapting WISE to support the learning goals critical to their context, while all users are leveraging the web-based environment to engage users in science inquiry learning and to generate research on technology-enhanced learning processes and instruction.

Table 1. Knowledge Integration rubric for scoring Energy Stories.  
Energy Story

<p>Write a story to explain how the earth is warmed by energy. Include: Where energy comes from How energy moves Where energy goes How energy changes/transforms</p>		
<i>Knowledge Integration Score</i>	<i>Level</i>	<i>Description</i>
1	<i>Irrelevant</i>	Does not answer the question being asked, or chooses not to answer
2	<i>Non-normative</i> ideas or links, vague ideas, or scientifically invalid connections between ideas	Energy comes from the Earth's core
3	<i>Partial link</i> Unelaborated connections using relevant features OR Scientifically valid connections that are not sufficient to solve the problem.	Includes correct energy source and destination ( <i>Energy comes from the sun and goes to the Earth</i> ) but does not adequately explain the mode of energy transfer or the role of energy transformation
4	<i>Full link</i> One scientifically complete and valid connection	Includes correct energy source destination ( <i>Energy comes from the sun and goes to the Earth</i> ) and explains ONE of the following: the mode of energy transfer ( <i>by radiation through space</i> ) OR the role of energy transformation ( <i>light energy changes into heat energy then IR</i> )
5	<i>Complex link</i> Two or more scientifically complete and valid connections	Includes correct energy source destination ( <i>Energy comes from the sun and goes to the Earth</i> ) and explains the mode of energy transfer ( <i>by radiation through space</i> ) and the role of energy transformation ( <i>light energy changes into heat energy then IR</i> )

Table 2. Step Types in the WISE4 Authoring Tool

Brainstorm Discussion	Students post their answer for everyone in the class to read and discuss
Branching	A branching point to control students' navigation through the project.
Car Graph	Lets students draw graphs and have cars move according to the graph
Challenge Question	Students answer a multiple choice question. If they get the answer wrong, they will need to revisit a previous step before trying again.
Data Graph	Students enter data values and generate a graph
Draw	Students draw using basic drawing tools, take snapshots and create flipbook animations
DuplicateNode	Description not provided
Explanation Builder	Students use ideas from their Idea Basket to generate a response
Fill In	Students fill in the missing text blanks in a body of text

Flash	Embed Flash content in a WISE step.
Graph/Sensor	Students plot points on a graph and can use a USB probe to collect data
Idea Basket	Students view their Idea Basket and are prompted to add an idea
Match & Sequence	Students drag and drop choices into boxes
Molecular Workbench	Students work on a Molecular Workbench applet
Multiple Choice	Students answer a multiple choice question
My System	Students work on a diagram where they can add images and connect them with lines
My System 2	Students work on a diagram where they can add images and connect them with lines (Version 2)
Open Response	Students write text to answer a question or explain their thoughts
Outside Url	Students see a webpage from the internet
Questionnaire	Students answer a collection of questions that require text or multiple choice answers
Reflection Note	Students write text to answer a question or explain their thoughts
Seasons	Seasons Visualization- students can experiment with different parameters and learn the effect of the tilt of the earth has on seasons
Surge	SURGE Physics Game step
Table	Students fill out a table
Template	This is a generic step only used by developers
Text/HTML Page	Students read information from an HTML page

Table 3. WISE Sequences of Step Types to Support Inquiry Activities

<b>Reading and writing prompts</b> direct students to attend to key information	
Predict, Observe, Explain, Reflect	The prediction pattern guides students' interpretation of texts (Linn, 2006). Students write and justify predictions for a scientific phenomenon, describe observations of the data collected, use evidence from observations to explain changes to their prediction, and finally, reflect on how this approach helped them learn.
Critique, Feedback	Students develop criteria to evaluate divergent claims in terms of the style and purpose of the text, and their sources of evidence. Based on these criteria, they write critical responses to the work of their peers.
Science narratives	Students write coherent narratives that require them to select key events, and to attend to their order and coherence.
Challenge questions [Figure 4]	Students evaluate the quality of different scientific explanations and are automatically redirected to relevant activities to improve their understanding
<b>Argument organizers</b> help students compose coherent narratives to make sense of complex phenomena	
Idea Manager (IM) [Figure 6]	Graphic organizer that guides the evaluation of evidence in terms of content, source, and connection to claims, and its integration into coherent arguments (Clark et al, 2009). The <i>Idea Basket</i> (IB) provides a persistent space for students to collect and sort multimedia information gathered from different locations in a module. Tags allow students to sort ideas into conceptual categories, and flags help them evaluate ideas according to specific criteria. The <i>Explanation Builder</i> (EB) is an organizational space presented at culminating moments during a module to scaffold students in sorting the evidence in their Idea Basket to form a coherent argument or to compose a sequence of events in a process.

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WISE Journal	A persistent space to practice informal, but routine articulation and recording of ideas. The Journal supports the development of extended arguments. In coordination with the other tools in the WISE suite, students can collect and generate multimedia texts (e.g., narratives, diagrams, animations). Much like an electronic portfolio, the Journal encourages students to revisit their thinking, reflect upon their ideas, and revise their reasoning by integrating new evidence encountered.
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**Explanation generation tools** allow multiple expressive means of communication

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WISE Draw, Flipbook Animator, Snapshot Tool	With tools for capturing and creating multimedia texts (e.g., drawings, animations, narratives), students are guided to translate their arguments into different representational forms. By doing so, they practice selecting and articulating key information, and learn the affordances of different media for communicating different messages and for different purposes (Nasir et al.)
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MySystem	A diagramming tool to visualize sequences of events, and guide the writing of verbal narratives. Translating between different representational forms helps students recognize both the abstract structure of narrative, as well as the key content details.
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**Informational features** add compelling ideas

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Multimedia texts	Curriculum designers can customize and embed media-rich content relevant to the target content into any module (e.g., interactive models, simulations, animations, still images, diagrams, graphs, videos, external webpages, and narrative text). Supported by other scaffolding tools and activities, students gain fluency in abstracting information from various text forms.
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**Activity templates** help teachers structure productive student interactions

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Inquiry, role-play	All module activities center around personally meaningful driving questions, for which students take on roles of scientists to investigate compelling phenomena. Providing such authentic and engaging experiences can help students self-identify with science. They may then view science as accessible, and a potential career option, which can enhance their motivation to achieve (Dweck, 2008).
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Peer critique, Peer feedback	Practice generating criteria and giving useful feedback on other's work helps develop skills in critically evaluating and responding to texts of various sorts, as well as in collaboratively building knowledge (Sato & Linn, 2010). The WISE system automates student pairings, which can otherwise be difficult to manage in large classrooms.
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Debate, brainstorm, discussion	Students share written explanations and feedback with their peers for various kinds of collaborative activities. They are encouraged to elaborate and build upon one another's ideas.
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Virtual experiment	Prompts and graphic organizers scaffold students' interactions with simulations and models of scientific phenomena. Similar to the activities of professional scientists, students plan and conduct experiments, and gather data to support their claims.
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Quests	Optional activities that extend beyond and across modules. Quests challenge students to independently seek further information, and to apply what they learned to new situations. Students can attempt quests when they complete the required WISE activities.
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1 This material is based upon work supported by the National Science Foundation under grants No. DRL-1119670 (CLASS), DRL-0918743 (VISUAL), DRL-0822388 (CLEAR), ESI-0334199 (TELS). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation, the Department of Education, National Academy of Education, or Spencer Foundation.