Chapter 9
Research on Critique and Argumentation from the Technology Enhanced Learning in Science Center

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Introduction

This chapter provides an overview and synthesizes research on critique, argument construction, and argumentation from the Technology Enhanced Learning in Science Center (TELS). TELS received funding from 2003 to 2010 by the US National Science Foundation to investigate approaches for improving learning and instruction in science classes for students in grades 6–12 with a focus on the role that information technology can play. TELS institutions included UC Berkeley, Concord Consortium, Arizona State University, Penn State, Technion, North Carolina Central University, and many others.

The work in TELS was guided by the knowledge integration (KI) framework (Linn & Eylon, 2006). This framework involves four main components: (1) eliciting current ideas, (2) introducing new ideas, (3) developing criteria for evaluating ideas, and (4) sorting and reorganizing ideas. Research and development in TELS applied and analyzed approaches and design principles based on this framework for supporting students and teachers engaging in inquiry with combined simulations, hands-on data collection, and other sources of information to make sense of complex science phenomena. Most of the curricular projects developed as part of TELS incorporated critique, argument construction, and argumentation in alignment with this framework, particularly in the context of helping students make sense of data they collected through visualizations, labs, and other evidence sources. In support of these efforts, several TELS researchers focused their research on the integration of critique, argument construction, and argumentation in TELS projects.

The first section of this chapter provides an overview of the web-based inquiry science environment (WISE), which was the principal context for much of the TELS work. The chapter then summarizes and synthesizes TELS research on critique, argument construction, and argumentation. Following our discussion of the TELS research on critique, argument construction, and collaborative argumentation, the

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chapter discusses the implications of these findings in terms of the overarching knowledge integration framework and future work.

Web-Based Inquiry Science Environment (WISE)

Much of the work in TELS was organized and conducted within the WISE environment. We therefore provide an overview of the WISE environment to provide context for subsequent discussion of research on critique, argument construction, and argumentation that TELS conducted in WISE. WISE is a powerful digital platform for multiple users and purposes (Fig. 9.1). It supports research innovation and teacher customization of inquiry activities in science classrooms. TELS researchers use WISE to design and develop inquiry-based online curricula. Teachers can adapt, customize, or create WISE curricula to address their local needs. Teachers use the same WISE platform to implement WISE curricula, assess their students' work, and share their experience with other WISE teachers. In addition to English,

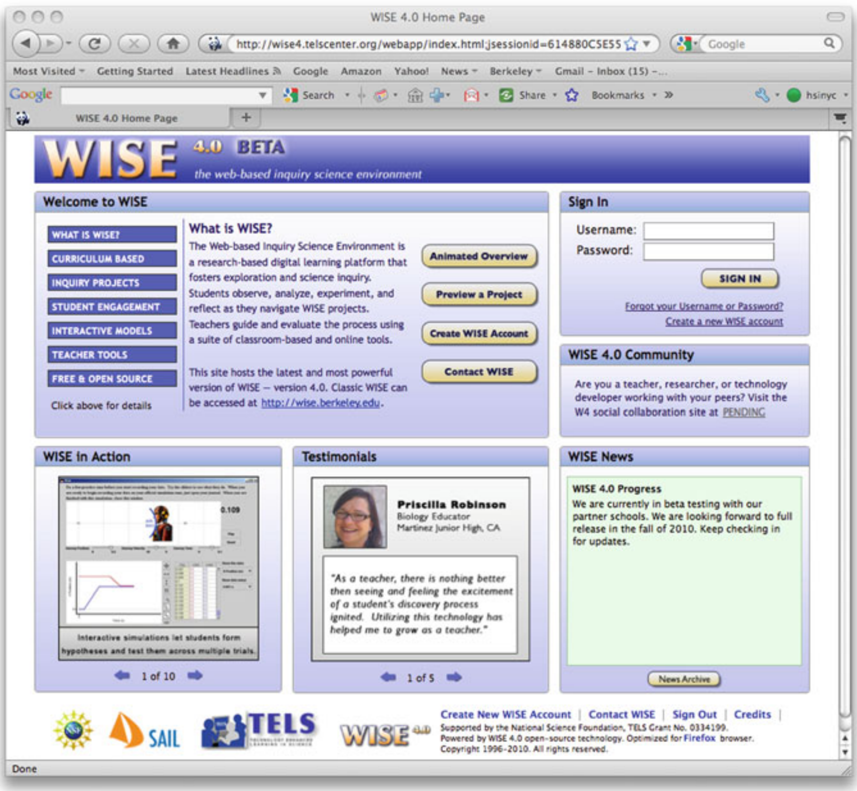

Fig. 9.1 WISE homepage

WISE includes projects in many languages such as Chinese, Dutch, Korean, and Norwegian. There are currently more than 20 developed projects in the main WISE project library on topics of physics, chemistry, earth science, biology, and physical and life science for high school or middle school students, available as open resources for teachers to use along with thousands of customized projects that various teachers and groups have created for their own contexts. WISE also supports international customization (Chang & Linn, 2010; Fig. 9.2).

The KI framework (Linn & Eylon, 2006) guides the design of WISE projects. In general, WISE projects have three main features. First, the *WISE inquiry map* reveals the structure of a WISE project and the learner's current activity and step (Fig. 9.3). The inquiry map guides students through a variety of activities and steps including visualization steps, modeling steps, reflection steps, evidence steps, and so forth. A series of steps can be aligned together to promote the KI process. For example, a series of predict–observe–explain (POE, White & Gunstone, 1992) steps can help elicit students' ideas before their observation and connect students' ideas to the new ideas after the observation step. Second, *highly interactive visualizations* enhance student learning of abstract or complex scientific concepts or phenomena that involve large-scale or unobservable levels. In the *Thermodynamics* project, for example, an interactive visualization about the molecular movement between objects with different temperature helps students learn the mechanism

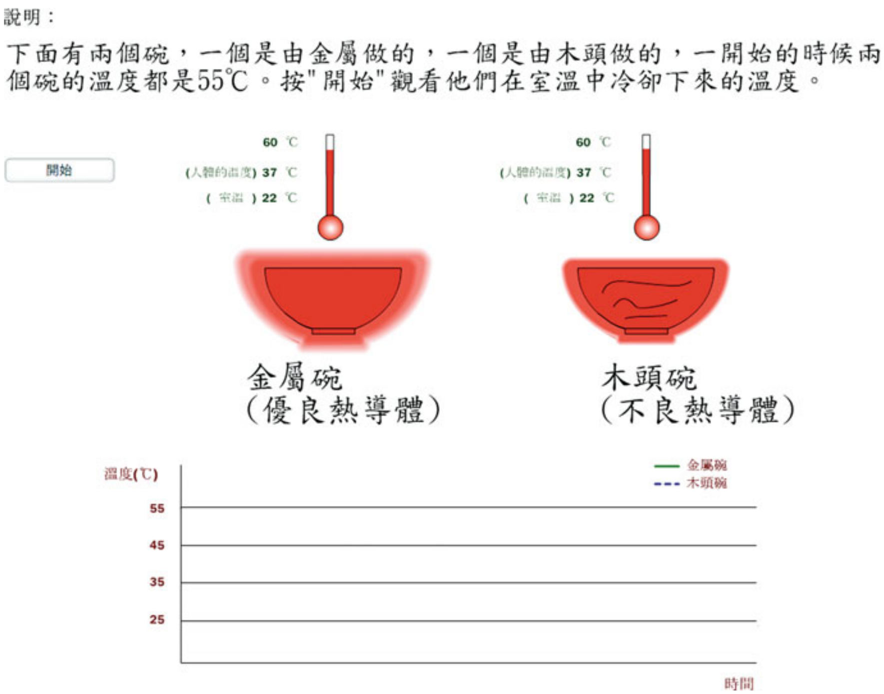

Fig. 9.2 The Chinese version of the WISE *Thermodynamics* unit

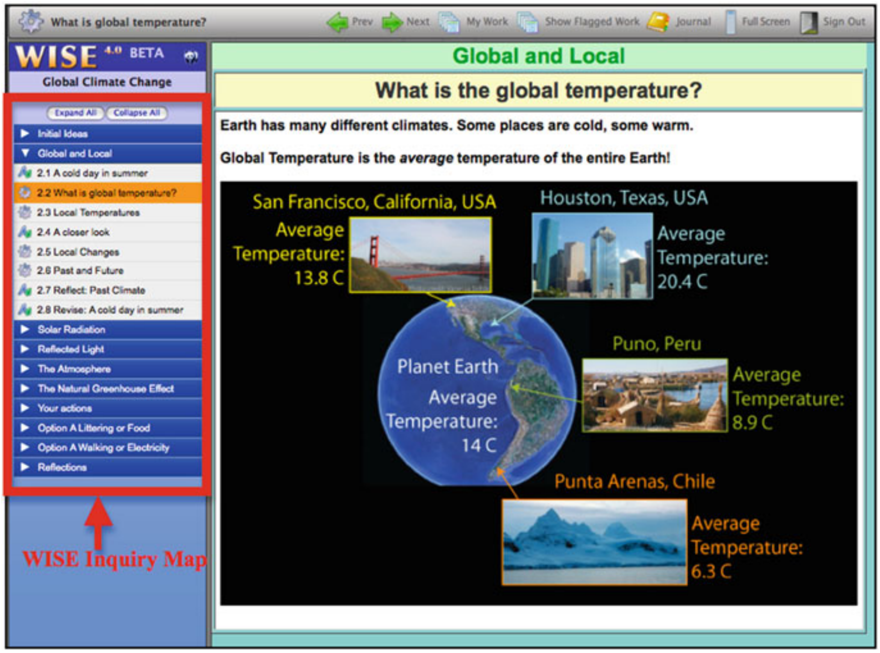

Fig. 9.3 WISE inquiry map

of heat transfer at the molecular level (Chang & Linn, 2011; Clark, 2006; Clark & Sampson, 2007, 2008) (Figs. 9.4 and 9.5). Finally, WISE projects incorporate embedded assessments to make students' thinking visible and to support students in developing conceptual understanding, decision-making, and inquiry abilities. Types of WISE embedded assessments range from multiple-choice items to open-ended textual or drawing items for curricular designers to choose from based on their needs. It is imperative for teachers to see evidence of how students are doing on the embedded assessments to help the teachers adjust their teaching and help students learn. Online feedback from the computer or the teacher helps students reconcile, reflect on, or sort their ideas.

The WISE platform supports researchers in conducting iterative design experiments (Brown, 1992; Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003) and accumulating and managing research data. WISE curricula have undergone multiple iterations of designing, implementing, assessing, and refining in multiple classrooms and other educational settings. Research indicates an overall significant effect of WISE curricula over traditional instruction on students' achievements in science (Linn, Lee, Tinker, Husic, & Chiu, 2006). The study by Linn et al. (2006) reported on 12 WISE units and assessments. Each unit required about one week of class time. They compared two large time-delayed cohorts of students from schools that serve English language learners, students underrepresented in science, and students receiving free or reduced price lunches. TELS administered assessments shortly

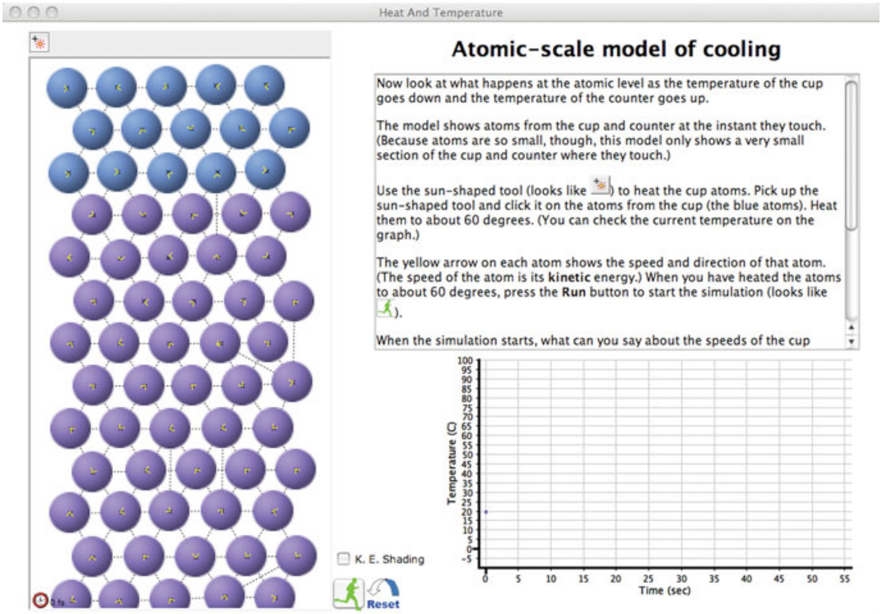

Fig. 9.4 The observation visualization

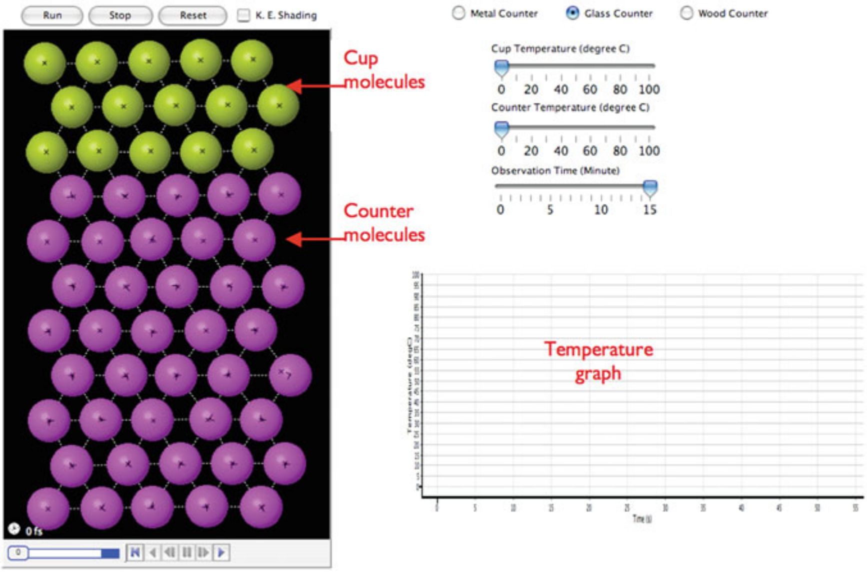

Fig. 9.5 The interactive visualization

after recruiting the teachers in the spring semester of the first year. In the following year the 25 teachers implemented the WISE units and administered the same assessments to the new cohort of students. Overall, the TELS cohort outperformed the typical cohort (effect size: 0.32, $p < 0.001$; Linn et al., 2006).

TELS Research on Critique

Scientific inquiry can be conceived as a knowledge building process where explanations are constructed to make sense of data and then presented to the broader community for critique, debate, and revision (Driver, Newton, & Osborne, 2000; Duschl, 2007; Passmore & Stewart, 2002; Sandoval & Reiser, 2004; Stewart, Cartier, & Passmore, 2005; Vellom & Anderson, 1999). Critique is thus a critical part of understanding the inquiry process and can potentially be harnessed in support of helping students make sense of complex science concepts. TELS research on critique has focused on (1) the potential of critique to support students as they conduct virtual experiments, (2) the effects of drawing and critique on enhancing student learning with dynamic visualizations, and (3) the integration of content knowledge through critique-focused concept maps.

Use of Critique to Support Students in Conducting Virtual Experiment

The first area of research on critique focuses on supporting students as they conduct virtual experiments. Interactive dynamic visualizations can engage students in conducting scientific experiments around visualizations to learn abstract scientific concepts or unobservable scientific phenomena. However, purposefully conducting virtual experiments to gain understanding in science is a challenge task for many students. For example, increasing the interactivity of a computer visualization allows students to change parameters of the visualization, but this openness may introduce extra difficulties. Students often use trial-and-error as opposed to mindful strategies (Chang & Tsai, 2010). Scaffolding can support students in efficiently conducting virtual experiments to develop adequate conceptual understanding. Research suggests coupling highly interactive visualizations with metalevel learning activities, such as self- or peer-evaluation (Chang, Quintana, & Krajcik, 2010; Moreno and Valdez, 2005) or critique (Chang, 2009; Chang & Linn, 2011) to help students reflect on and refine ideas (Linn, Chang, Chiu, Zhang, & McElhaney, 2011). More studies are needed to investigate how to design effective learning environments supportive of critique.

Questions. How effective are scaffolded critique activities in supporting students' understanding in science? How do students critique virtual experiments attributed to others?

Context. The TELS research by Chang (2009) and Chang and Linn (2011) used the WISE (Linn & Hsi, 2000; Linn, Davis & Bell, 2004) unit called

"Thermodynamics: Probing Your Surroundings" (Clark, 2006; Clark & Sampson, 2007, 2008). The unit begins with a thermal equilibrium hands-on experiment where students select six objects in the classroom, predict the temperatures of the objects, and then measure the temperatures using a thermal probe. Next students experiment with molecular workbench visualizations to explain heat transfer. Then students generate principles to explain patterns they observed in the temperatures of the objects and how hot or cold they felt. The final activity engages students in discussing their principle with peers and reflecting on how to revise their principles.

This one-week online inquiry project initially featured the observation version of the molecular workbench (Xie & Tinker, 2006) visualization (Fig. 9.4). Using the visualization students can observe how the molecular movement and temperature graph change when a hot cup is placed on a cold counter. Chang (2009) and Chang and Linn (2011) modified the visualization to create the interactive and critique versions while maintaining the one-week duration. In the interactive version the revised visualization (Fig. 9.5) allows students to change values of four variables to conduct virtual experiments with the visualization: (1) the counter material (metal, glass, or wood), (2) the cup temperature, (3) the counter temperature, and (4) the time of the experiment. In the critique version instead of reading guidelines about how to conduct the virtual experiments, students were guided to critique a fictitious student's, Mary's, experiment before conducting their own virtual experiments.

Methods. The study involved two science teachers and their 205 eighth-grade students in seven classes at two public middle schools in California. One teacher was able to randomly implement the critique and interactive conditions and the other teacher chose to run the observation version due to technical issues at the school. As a result, three classes used the critique version, two classes used the interactive version, and another two classes used the observation version. Data collected and analyzed included all students' responses to the pre- and posttests and embedded assessments.

Findings. How effective are the scaffolded critique activities to support students' understanding in science? The study compared student performances among the three conditions to discern the added value of critique. Effect sizes between the pre- and posttest scores for the three conditions ranged from moderate for the observation, $d = 0.57$, and interactive conditions, $d = 0.63$, to large for the critique condition, $d = 1.21$. However, a teacher or school effect might exist since the observation condition was implemented in one school while the interactive and critique conditions were implemented in a different school. On the other hand, the contexts in interactive and critique conditions were comparable. Using ANCOVA to control for differences in pretest levels, the critique condition outperformed the interactive condition on the total posttest scores [$F(1) = 6.53$, $p = 0.012$]. The results indicate that the virtual experiments were effective when coupled with the critique activity.

How do students critique virtual experiments attributed to others? The students in the critique condition showed that they were able to suggest better methods for Mary's experiment but were less successful in evaluating the interpretation of the experiment. Students demonstrated understanding of strategies such as selecting extreme values to make experimentation results significant. However, only 7% of the students related evidence from the visualization to Mary's interpretation. Moreover, rather than specific criticisms, most students responded that more experiments are better regardless of the research question.

Implications. The study provides evidence for the benefit of critique. Critique directs students to pay attention to the design of the experiment whereas conventional instruction often directs attention to producing experimental results. As students critique, they distinguish their own ideas from those attributed to Mary and develop criteria for virtual experiments.

Promoting Learning with Dynamic Visualizations: Drawing and Critique

The second area of TELS research focused on critique examined and contrasted drawing and critique as tools to support learning with dynamic visualizations. Dynamic visualizations have great potential to support science learning because they can demonstrate unseen processes (Ardac & Akaygun, 2004; Sanger, Brecheisen, & Hynek, 2001; Williamson & Abraham, 1995). Adding visualizations to instruction can increase interest and insights in science (Boo & Watson, 2001; Corliss & Spitulnik, 2008), but some researchers also warn that the impact of dynamic visualizations may not always be powerful (Tversky, Morrison, & Betrancourt, 2002). Some visualizations represent dynamic information in such an apparently simple way that learners may become convinced they understand based on superficial observations (Chiu & Linn, in press). To enhance learning with visualizations, students must observe carefully, analyze what they see, and develop criteria to decide what information to be integrated. Generating drawings has been suggested as an effective way to promote learning with visualizations (Zhang & Linn, 2008). In the present study, Zhang designed a critique activity and explored the effect of critique on enhancing student learning with visualizations.

Questions. Does critique promote student learning with dynamic visualizations? What are the effects of drawing and critique on enhancing student learning about chemical reactions with dynamic visualizations?

Context. This research was conducted during a 5-day TELS project entitled *Hydrogen Fuel Cell (HFC) Cars*. Informed by the knowledge integrate framework (Linn & Eylon, 2006), this project illustrates chemical reactions within the context of HFC cars. It starts by eliciting student ideas about gasoline powered cars and then employs different representations to introduce chemical reactions, including a video showing the burning of a hydrogen balloon, a visualization of hydrogen combustion at the molecular level (see Fig. 9.6), and a flash movie of the reaction inside HFCs. Finally, students participate in an online discussion about the advantage and disadvantage of the two cars.

Methods. Three classes of high school chemistry students participated in this study (N = 73). The classes, taught by the same teacher, were randomly assigned to one of drawing or critique groups to study HFC.

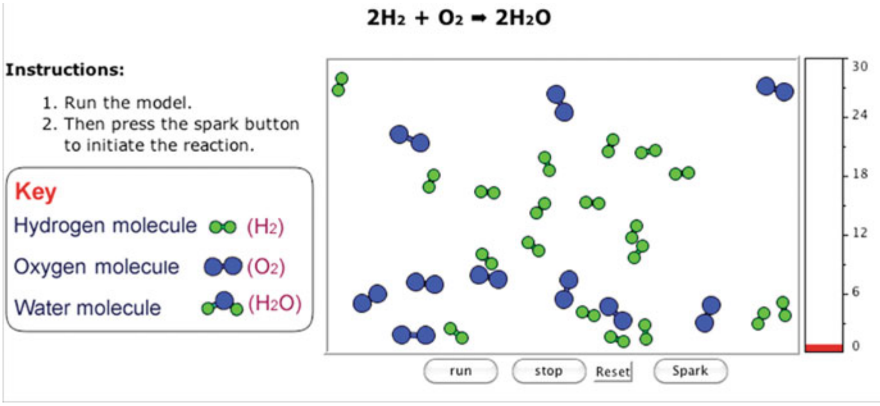

Fig. 9.6 Screenshot of the hydrogen combustion visualization

On the third day of the HFC project, students first learned chemical reactions by exploring the dynamic visualization about hydrogen combustion. Afterwards, students in the drawing group generated four pictures to represent intermediate phases during hydrogen combustion (Fig. 9.7). Students in the critique group critiqued two sets of drawings about hydrogen combustion processes (see Fig. 9.8 for one set of drawings and the critique question). Both groups completed the tasks within 40 minutes. During the remaining days of the HFC project, students in both groups worked on the same tasks of the project.

To assess student learning with the visualization, all participants were asked to complete the same tests before and after the project. The test includes three types

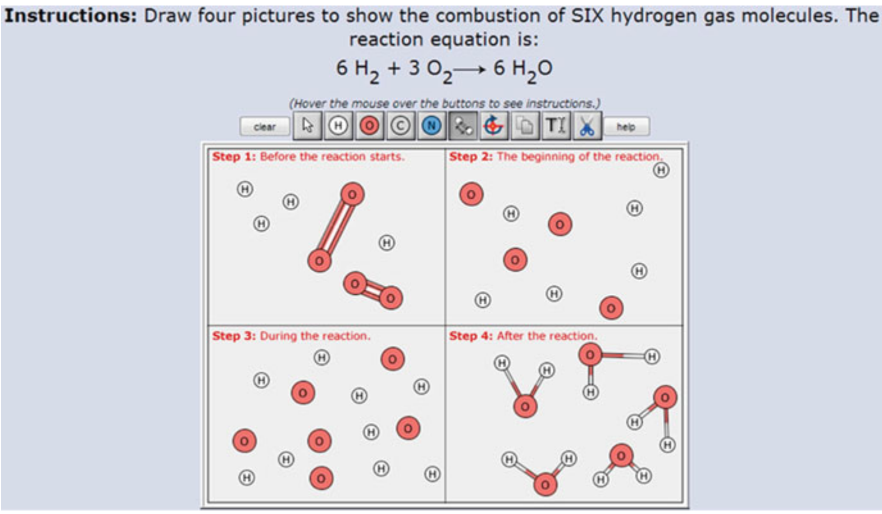

Fig. 9.7 Screenshot of the drawing activity

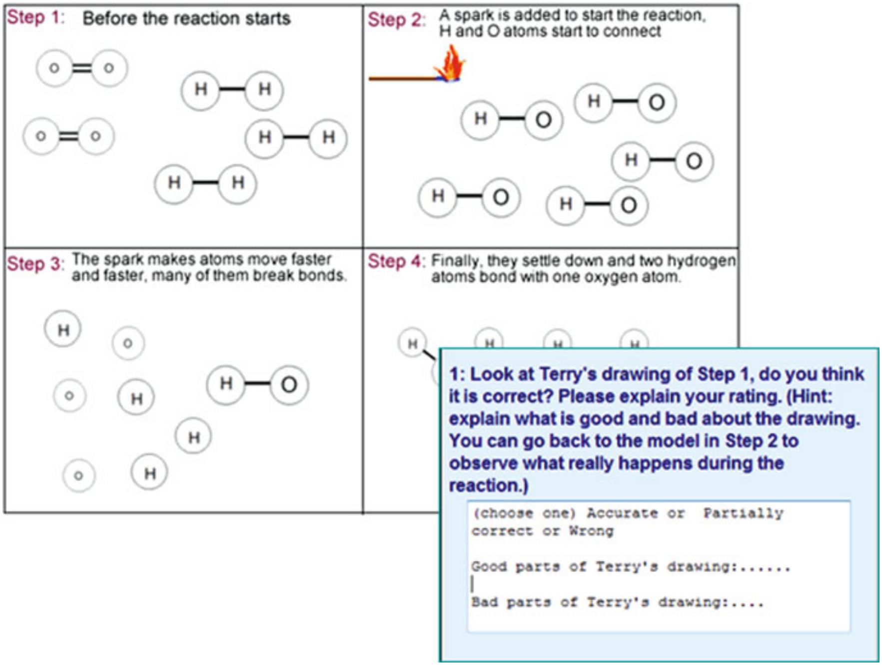

Fig. 9.8 Screenshot of the critique activity with a sample critique question

of questions: (1) items to assess content knowledge about hydrogen combustion, (2) drawing items asking students to draw how the reaction between nitrogen and hydrogen gas takes place, and (3) critique items asking students to evaluate drawings about methane combustion. The first type of questions examines student knowledge about hydrogen combustion they have learned from the HFC project. The other two types of questions assess whether students can apply their knowledge to explain other chemical reactions.

Findings. Students in both groups achieved similar gains after the HFC project. Comparison of student performance on different types of questions revealed important information of student learning. Students who drew exhibited larger gains on items that assess knowledge about hydrogen combustion and smaller gains on critique items. For drawing items, students in both groups achieved similar gains. The findings suggest that critique is as effective as drawing in supporting student learning with visualizations. Compared to those in the critique group, students formed deeper understanding about hydrogen combustion by generating pictures about it. Students who critiqued performed better in terms of applying their knowledge to explain other chemical reactions.

Implications. The results indicate that both drawing and critique are effective approaches for promoting student learning. One hypothesis is that both drawing and critique encourage students to develop criteria to distinguish among ideas. Drawing requires students to generate pictures about the details of hydrogen combustion. To accomplish this task, students need to distinguish among their own ideas and new information from the visualization to determine what to draw. They may revisit the visualization and observe carefully to help develop the criteria. Critique prompts students to evaluate some pre-made drawings. To critique, students need to analyze ideas represented in the given drawings, compare with their own ideas, and decide how to evaluate. They may also revisit the visualization to help establish criteria. The success of drawing and critique indicates that it is crucial to encourage students to develop criteria to distinguish among ideas. Further study should focus on examining what criteria are generated by students and how they are associated with learning.

Integrating Biological Knowledge Through Critique-Focused Concept Mapping

The third TELS area of research related to critique involves critique-focused concept mapping to support students in integrating biological content knowledge. Modern biology, genetics, cell biology, and evolution have been found to be conceptually difficult domains to teach and learn (Bahar, Johnstone, & Hansell 1999; Tsui & Treagust, 2003). They form a complex system with multiple interacting levels (Wilensky & Resnick, 1999). Coherent integration of such complex systems requires understanding of both the concepts and the connections between concepts. Dynamic computer-based visualizations with interactive inquiry activities allow students to explore the nature of ideas (Ainsworth, 1999). Concept maps allow making the connections between ideas within and across levels explicit (Novak, 1996).

Creating coherent concept maps is not a one-shot activity, but requires a subsequent revision step (Schwendimann, 2007). Revision activities require students to generate criteria (Chi, 2000; Linn & Eylon, 2006) that allow comparison against a benchmark. Benchmark concept maps can be generated by experts or novices.

Expert maps model expert behavior by connecting multiple levels and focus on underlying principles (Hmelo-Silver, Marathe, & Liu, 2007). On the other hand, peer generated work uses often more familiar language (Keppell, Au, Ma, & Chan, 2006) and might support deeper critical evaluation as it does not hold authoritative power over other's work. Peer evaluation can be mutually beneficial for the giver and the receiver (Topping, 2005).

Schwendimann's study compared two different critique activities: expert-generated benchmark map versus peer-generated benchmark map. Schwendimann's study used the KI (Linn & Hsi, 2000; Linn, Eylon, & Davis, 2004) in terms of focusing on connections between and distinction of a diverse repertoire of ideas.

Questions. How do expert and peer critique activities impact learning from a dynamic visualization? What connections among biology concept do students make in each condition? What criteria do students use for expert and peer critique?

Context. The week-long curriculum unit, Space Colony—Genetic Diversity and Survival, was designed in the WISE (Linn et al. , 2004). The unit consists of seven activities that emphasize connections between cell division, the underlying genetic processes, and the overarching evolution principles (Fig. 9.9). The unit includes a flash-based visualization “Evolution Lab” (biologyinmotion.com) (Fig. 9.10) that enables students to run experiments about the effects of mutations, natural selection, and evolution.

Students receive initial training in the concept mapping method. Following the visualization, students work in dyads to create a paper-based concept map from six given concepts. Students first place them in the appropriate level area (DNA, cell,

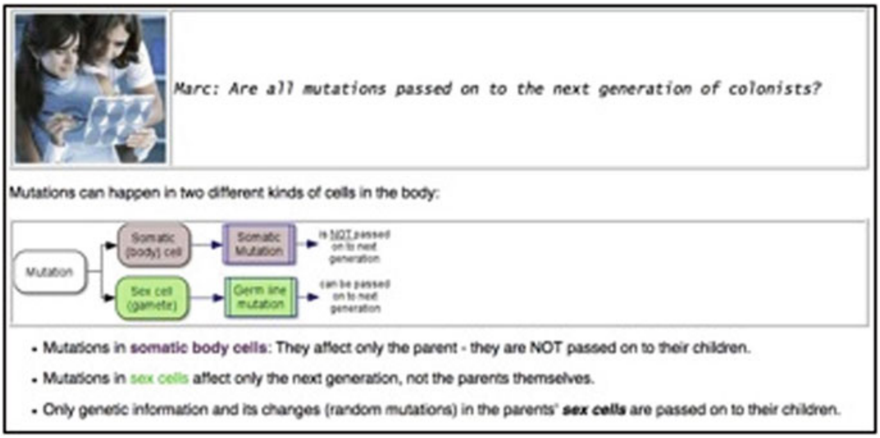

Fig. 9.9 Screenshot of WISE module space colony

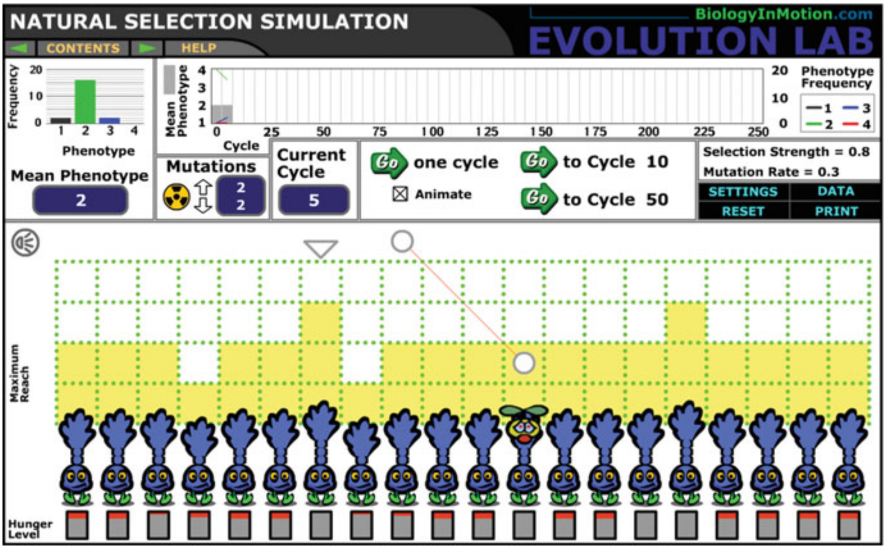

Fig. 9.10 Evolution lab visualization

or organism/population) and connect them with labeled arrows. Students then revise their map by comparing it against an expert- or peer-generated benchmark concept map. Students developed their own criteria.

Methods. The curriculum was implemented by two teachers with two ninth/tenth grade biology classes each in one public high school ($N = 81$) in the western United States. One class by each teacher was randomly selected for each treatment (expert or peer map comparison).

Pre- and posttests consisted of nine multiple choice and explanation items that assessed changes in students' connections between genetic and evolution concepts. Tests were coded using a five-scale KI rubric (Linn et al., 2006).

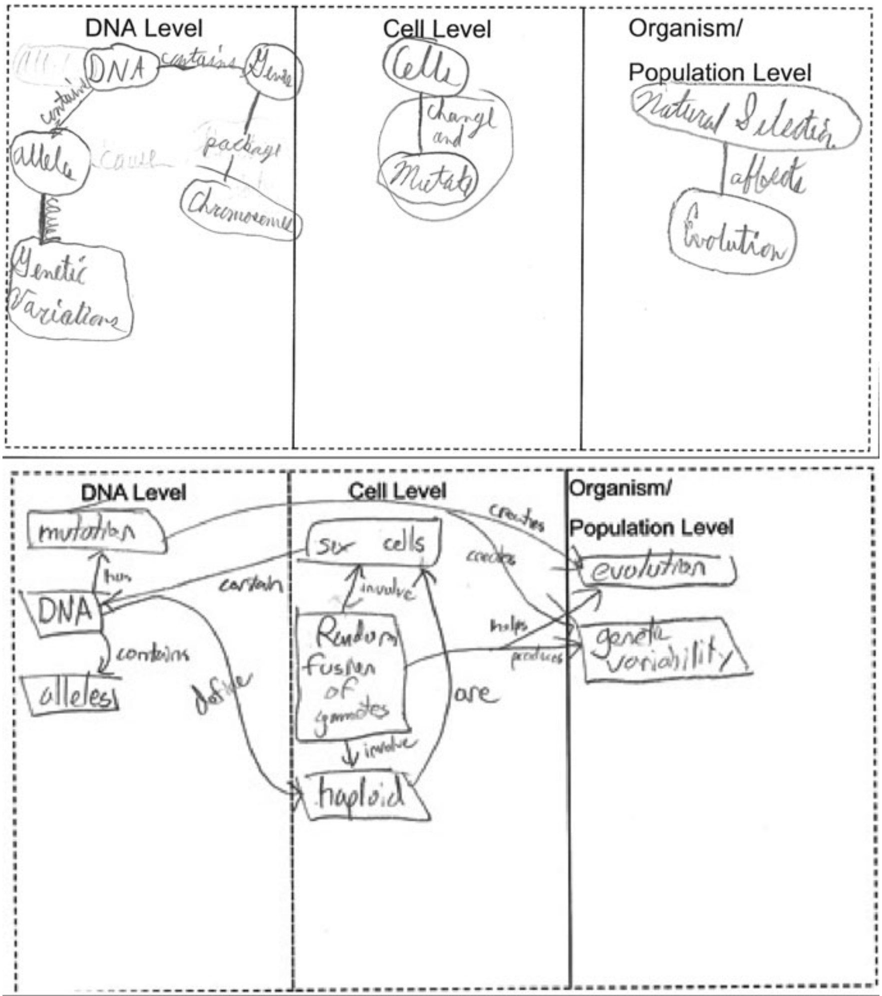

Fig. 9.11 Concept map before and after revision

Concept maps propositions were coded on a five-scale KI rubric for concept maps (Schwendimann, 2008). The rubric distinguished between link label, link direction, concept placement, and cross-links.

Findings. The results suggest that the combination of critique-focused concept mapping and a dynamic visualization helped students in both treatment groups generate novel connections across levels. Neither treatment groups differed significantly in their posttest performance. In their revised maps, the peer-review group showed more across-level connections than the expert map group. Both treatment groups significantly improved their concept maps through the critique activity [paired $t(80) = 4.13$, $p < 0.0001$ (two-tailed)] (Fig. 9.11).

Students in both treatment groups generated a broad variety of criteria to review and compare different aspects of concept maps. However, the groups differed from each other in the different kinds of criteria used to review their maps. This study suggests different mechanisms and criteria involved in the two critique activities. The two treatment groups differed in their use of different criteria (Fig. 9.12):

I. Students in the expert map group commented only on concept placement (61%) or missing link labels (27%). Both criteria were surface-level criteria that allowed for quick comparisons with the expert map. Critiquing other people's work is often easier than evaluating one's own work.
II. Students in the peer-map group showed a larger variety of criteria. Twenty-eight percent also criticized the misplacement of a concept and 18% pointed out a missing label, but another 28% suggested adding a missing link, and 5% analyzed the direction of an arrow. The peer-map activity engaged students to develop and use more criteria on a conceptual level, such as missing propositions

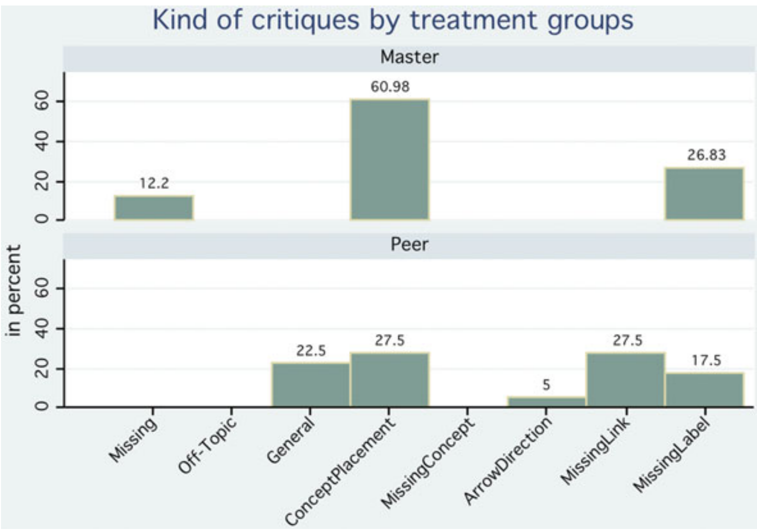

Fig. 9.12 Criteria generated by students in each treatment group

and causal directions. Comparing their own ideas against those of their peers helped students to value their own ideas while developing criteria to critically reviewing them.

Implications. Both critique methods lead to reflection through criteria generation and revision. Critical reflection supports students' self-monitoring of their learning progress. Self-monitoring is an important skill for autonomous life-long learning (Linn, Davis, & Eylon, 2004). Both surface and principle critique are important for learning. Using expert or peer benchmark work, or a combination thereof, can target specific forms of critique toward a more coherent understanding of biology.

TELS Research on Argument Construction

Generating a persuasive and convincing argument that coordinates evidence and theory in order to support or refute an explanation is an important part of the inquiry process (Driver et al., 2000; Duschl & Osborne, 2002; Jiménez-Aleixandre, Rodríguez, & Duschl, 2000; Kuhn, 1993; Kuhn, 1970; Latour, 1987; Siegel, 1989). For arguments to be considered persuasive and convincing, they must be consistent with the epistemological criteria used by the larger scientific community for "what counts" as valid and warranted scientific knowledge. Examples of central epistemological criteria in science include the importance of (a) evidentiary backing or rationales for knowledge claims and proposed tests of claims (Hogan & Maglienti, 2001), (b) coherence between theoretical frameworks and data (Passmore & Stewart, 2002), (c) establishing the credibility of evidence (Driver et al., 2000), (d) parsimony (Sandoval & Reiser, 2004), and (e) logically consistent and coherent reasoning (Zeidler, 1997). Research in TELS has focused specifically on how students warrant their claims.

How Do Students Substantiate Their Decision-Making About Community Science Issues?

Research has shown that multiple factors influence reasoning about complex science problems, such as genetic dilemmas, conservation practices, or personal and community health (Corburn, 2005; Grace & Ratcliffe, 2002; Zohar & Nemet, 2002). While science plays an important role in these issues, people often privilege other factors, such as morals and values, personal and familial gain, the uncertainty of available information, and predicted outcomes. Isolatable research methodologies identify whether students base their decisions on scientific or nonscientific knowledge (Fleming, 1986a, b; Grace & Ratcliffe, 2002; Zohar & Nemet, 2002). This study builds upon these and other integrated perspectives and investigates how students put forth multiple different perspectives, evidence that includes local knowledge, and tradeoffs to support their asthma-related decision-making.

Questions. How do students from three different local communities substantiate their decision-making?

Context. In the Asthma module, students explore the scientific dilemma of asthma by (1) constructing an integrated understanding of asthma as a community health problem and (2) practicing integrated decision-making about which asthma intervention to implement in their community. While studying the Asthma module, students are expected to engage in decision-making from multiple perspectives. In addition, students must use supporting evidence, localize the decision to specific communities, and consider tradeoffs. The Asthma project research explored how a multi-dimensional, multi-contextual methodology provides insight into students' decision-making. Table 9.1 summarizes the learning activities in Asthma module.

Methods. This study investigated 3 teachers and 108 students, across three local communities, C-town, B-Town, and R-Town. Table 9.2 summarizes the research participants and settings. The following decision prompts were embedded in three activities across the project to identify how students integrate their ideas to justify

Table 9.1 Overview of the asthma module activities and assessments

Activity	Description
1: Your asthma problem	Evidence pages and an interactive map introduce (a) the asthma problem in students' community, (b) the driving question, and (c) the diesel reduction & asthma clinic interventions
2: How does asthma affect the body?	Dynamic visualizations explain the physiology of breathing and asthma
3: What causes an asthma attack?	Static visualizations explain asthma triggers & the physiology of an allergic immune response
4: How does diesel exhaust impact your community's asthma problem?	Multiple pieces of evidence provide explanations about how diesel pollution impacts on asthma and general health
5: How can a person manage their asthma?	Multiple pieces of evidence provide explanations about how asthma management and health care can contribute to asthma-related hospitalizations rates
6: Improving your community's asthma problem	Students debate proposed solutions and generate new solutions

Table 9.2 Summary of research settings and participants

Community	School	Area	Teacher	Course	Year	# Classes	Grade	*N*
C-Town	Mountain High	Urban Fringe	Sandals	Biology	2	2	9	40
B-Town	Bayview High	Urban	Pebbles	Anatomy & Physiology	2	2	10	34
R-Town	King High	Urban	Nelson	Biotechnology	3	2	11–12	34

their decisions about which program will better solve their community's asthma problem:

- Which program do you want your City Council to support? Asthma Clinic or Diesel Reduction Program
- How will this program better serve your community?
- What evidence (information) helped you make this decision?

Explain your answer.

The decision note assessment items elicited multi-dimensional responses from students. In response, KI rubrics were created for each dimension: perspectives, evidence use, tradeoffs, and localization (see Table 9.3).

Findings and Implications. Student decision-making about the asthma problem varied throughout the module and differed across communities. Table 9.4 reports the mean KI scores for each dimension. Table 9.5 summarizes the interpretation of these results with regard to decision, perspectives, evidence use, consideration of tradeoffs, and localization.

While students across all communities justified their decisions similarly, they differed in the programs they supported. Students probably varied in the programs they supported because they held preliminary ideas about asthma and their community. Also, students may have initial notions about what an effective program entails. Students switching their decisions indicates that they are grappling with ideas about the asthma problem and which solution to implement in their community. When students learn from the Asthma module, their teachers, and their peers, they have the opportunity to replace, isolate, or integrate a wide range of ideas. This restructuring of knowledge likely influenced which program they chose to support. Also, students may differ in when they change their decision because they may perceive some pieces of evidence as more compelling than others. These findings suggest the design of the Asthma module creates a rich opportunity for students to engage in KI about an authentic community science problem.

In all three local communities, students primarily supported their decisions with ideas related to risk. This was consistent with R-Town and C-Town's primary and secondary perspectives when explaining asthma as a community problem. However, B-Town students explained the asthma problem from a prevalence perspective (Tate, 2009). This inconsistency suggests that students (a) have different criteria for what constitutes a community health problem and which program best addresses that problem or (b) hold many ideas about the asthma problem and have yet to sort them out and form a coherent, integrated understanding. Future refinements to the Asthma module should include learning activities that allow students to put forth and negotiate criteria for what constitutes a community health problem and effective solutions for their community.

While students differed in the ideas they put forth to support their decisions, students in all communities exhibited similar evidence use. Most students included at least one isolated piece of evidence to justify their decisions. Seethaler and Linn (2004) and Bell (2004) argue that within an appropriately scaffolded learning

Table 9.3 Knowledge integration (KI) rubrics and example of students' responses

KI score	Perspectives	Evidence use	Tradeoffs
2: No Integration	Students use reasons or evidence to explain the problem from one perspective. "This program is better for my community because our community has many highways, railroads, public transportation, machinery/factories, and refineries." (risk)	Students simply state that a program is better for their community; no elaboration or explanation. "The program is better for my community because it will help out people with asthma much better. It will save a lot people."	Students mention no tradeoffs. "This [Asthma Clinic] program is better for my community because it will benefit the people in our community without medical insurance to be treated for asthma problems. The evidence that helped me make this decision is before the clinic, 18/80 children and teenagers were hospitalized for asthma, and 1 year after the clinic no children or teenagers were hospitalized because of the asthma clinic."
3: Partial Integration	Students explain the problem from two or more perspectives but do not link them. "This program is better for my community because it will help those in need of help with no insurance. The evidence that helped me make this decision is the number of hospitalization visits because it has given people with asthma a chance to get treated" (risk-management)	Students explain why the program is better (or worse) for the community or include evidence that is not connected to a reason. "This program is better for my community because the causes of asthma would be more directly halted if people who are directly affected by asthma could come to the clinic and receive professional medical attention. Because my community is right next to the freeway."	Students mention a tradeoff but include no supporting evidence. "The Asthma Clinic benefits are limited to people who have asthma and no health insurance, while the Diesel Reduction Program has the potential to help all people in the community."

Table 9.3 (continued)

KI score	Perspectives	Evidence use	Tradeoffs
4: Simple Integration	Students link two perspectives. "This program is better for my community because there will be less smog output reducing the number of people who will get asthma." (risk-prevalence)	Students include a reason and supporting evidence. "This program is better for my community because it provides options for people who have asthma and is not limited to just people who have asthma not caused by diesel pollution. The evidence that helped me make this decision is the chart/picture that showed that asthma is NOT only caused by irritants. This chart helped me decide that because it showed me that asthma is not caused by only one type of thing."	Students include one tradeoff that is supported with evidence. "We think our City Council should support the Diesel Reduction Program because it will help all people who have asthma, as opposed to the Asthma Clinic which would only benefit those without health insurance. Also, a reduced amount of diesel in the air will help the environment as well as the number of asthma cases."

Table 9.3 (continued)

KI score	Perspectives	Evidence use	Tradeoffs
5: Complex Integration	Students link three or more perspectives. "This program is better for my computer because most people in my community have asthma due to many triggers not just due to diesel. The clinic will benefit those without health insurance. The evidence that helped me make this decision is that over 14,500 people in [the county] do not have insurance and have asthma." (prevalence- physiology, risk-prevalence)	Students provide 2 or more instances of reasons and supporting evidence. "This program is better for my community because it will help people who have asthma and don't have health insurance. It will also help people who's asthma is not caused by irritants. Other things that will improve are number of emergency room visits and hospitalizations by non-insured patients. This program will better serve our community because it will be easier for non-insured asthma sufferers to get medicine, information, and asthma-related checkups . . . Other pieces of evidence were the pages that described the two different types asthma, irritants, and allergens. This helped us make our decision by showing us that asthma is not only caused by PM or an irritant but by also pollen or allergens."	Students include 2 or more tradeoffs, each supported with evidence. This [Diesel Reduction] program is better for my community because it helps everyone. Although the asthma clinics help those without insurance, it only helps people with asthma. The diesel reduction program can prevent lung damage caused by diesel exhaust and overall reduce CO_2 in the atmosphere, which benefits everyone. The threat of global warming affects everyone while asthma affects less than 25% in [A] County. The evidence that helped me make this decision is what diesel does to you, your body your environment. When diesel is used in vehicles, the diesel particles that contain very harmful chemicals can get into your airways and make it hard for you to breathe. Also, people who live by streets or highways have a higher chance of having diesel exhaust affect all of them. This evidence helped us to relate the issue of diesel pollution to our own personal lives."

Table 9.4 Summary of a repeated measures ANOVA for decision justifications related to students' community's asthma problem

Community	Dimension	Decision Note 1	Decision Note 2	Decision Note 3	F	p[a]	Effect size[b]
R-Town	Index	8.5 (1.46)	9.44 (1.46)	8 (1.31)	6.14	0.06	0.30
	Perspectives	3.19 (1.11)	3.57 (0.96)	2.81 (0.91)	4.01	0.03	0.35
	Evidence	3.19 (0.40)	3.34 (0.5)	2.81 (0.54)	5.34	0.10	0.53
	Tradeoffs	2 (0)	2.19 (0.4)	2.19 (0.4)	1.55	0.23	0.38
C-Town	Index	8.6 (1.24)	9.27 (1.22)	7.73 (1.27)	6.72	0.004	0.53
	Perspectives	3.13 (0.92)	3.73 (0.80)	2.87 (0.52)	4.36	0.02	0.26
	Evidence	3.27 (0.46)	3.13 (0.35)	2.87 (0.52)	4.26	0.02	0.74
	Tradeoffs	2.13 (0.35)	2.33 (0.62)	2.13 (0.35)	1.14	0.34	0
B-Town	Index	8.71 (1.42)	8.62 (2.18)	9.19 (2.87)	0.84	0.44	0.22
	Perspectives	3.19 (0.98)	3.14 (1.24)	3.29 (1.38)	0.15	0.86	0.09
	Evidence	3.19 (0.51)	3.10 (0.70)	3.24 (1.0)	0.31	0.74	0.06
	Tradeoffs	2.19 (0.40)	3.24 (0.62)	2.48 (0.87)	1.90	0.16	0.40

[a] This p value represents the significance in change in scores over time.
[b] This effect size represents the magnitude of difference between the decision notes 1 and 3.

Table 9.5 Looking across communities: Summary of findings for decision justifications

	R-town	B-town	C-town
Decision[a] AC: DRP	Undecided →[b] Asthma Clinic 1:1 → 1:1 → 2:1	Diesel Reduction Program 1:3 → 2:3 → 1:2	Undecided → Asthma Clinic 1:1 → 2:1 → 3:2
Perspectives	Multiple, isolated RISK[c]/prevalence/ management[d] →RISK/prevalence/ management/physiology →RISK/management	Multiple, isolated RISK/physiology	Multiple, isolated RISK/management →RISK/physiology →RISK/management
Evidence	Partial support	Partial support	Partial support
Tradeoffs	Limited consideration	Limited consideration	Limited, but increasing consideration
Localization	Limited localization	Limited localization	Very limited localization

[a] An estimated ratio to illustrate student program choices at each decision note.
[b] The arrow represents changes across the online decision notes in the Asthma module.
[c] The term in all caps represents the primary perspective articulated by students in their explanation of the asthma problem.
[d] The term in lowercase letters represents the secondary perspective articulated by students in explanation of the asthma problem.

environment, students can construct evidence-based justifications. The findings reported here support this claim. Students made use of the evidence provided in the module to justify their decisions. While the module was successful with regard to the availability of evidence for students to learn and include in their decision justifications, additional or improved scaffolds are needed to encourage students to generate connections among their reasons and evidence. Students also need more opportunities to learn what constitutes a well-supported and integrated decision.

In general, students in all communities provided limited localization of their decision justifications. This lack of localization can be attributed to (a) the ambiguity of the term, “community,” (b) students’ assumptions that others know what “community” they are referencing, or (c) students’ unfamiliarity with the norms for constructing a decision justification about the asthma problem in their community. Students need more instruction from the Asthma module and teacher to explicitly localize their decision justifications. This may also include additional opportunities to negotiate and reach consensus about which aspect of the community they are addressing when they put forth and support their decisions.

Analyzing Students’ Arguments

In addition to our research on students’ construction of arguments, the TELS project also supported the preparation of a review of approaches used to analyze the quality of students' arguments (Sampson & Clark, 2008). The intent of this review was to provide an overview of several different analytic frameworks that science educators use to assess in terms of three focal issues: structure, justification, and content. To highlight the different foci, affordances, and constraints of these different analytic methods, the review of each framework included an analysis of the sample argument. Overall, this review highlighted how the divergent foci of the various frameworks result in different assessments of overall quality. It is therefore important for researchers to understand that analytic frameworks, such as the ones included in the review, (1) are tools created for specific tasks to investigate specific questions and (2) were originally designed for a specific context. Frameworks, as a result, are not fully interchangeable, and the foci of each framework require consideration before comparing the results of various studies.

This review also highlighted a number of overarching messages regarding the current nature of research in the field. First, the analytic frameworks available tend to focus on atomized aspects of students' arguments. While this type of emphasis has proven fruitful, future research will need to also include more holistic considerations of the quality of the arguments that students produce as part of the

Directions: The first three questions are designed to determine what you think counts as a good *scientific* argument. In each question you will be given a claim. Following the claim are 6 different justifications. Your job is to rank the justifications in order using the following scale **(For each question, you can only use each ranking once)**:

1 = This is the **most** convincing justification
2 = This is the **2nd most** convincing justification
3 = This is the **3rd most** convincing justification
4 = This is the **4th most** convincing justification
5 = This is the **5th most** convincing justification
6 = This is the **least** convincing justification

Question #1. Your task is to rank these 6 different justifications in terms of how convincing you think they are. Remember that you can only rank one justification as 1, one justification as 2, one justification as 3, and so on.

Claim: Objects that are in the same room are the same temperature even though they feel different because…	**Your Ranking**
…when we measured the temperature of the table, it was 23.4°C, the metal chair leg was 23.1°C, and the computer keyboard was 23.6°C.	________
…good conductors feel different than poor conductors even though they are the same temperature.	________
…objects that are in the same environment gain or lose heat energy until everything is the same temperature. Our data from the lab proves that point: the mouse pad and plastic desk were both 23°C.	________
…objects will release and hold different amounts of heat energy depending on how good of an insulator or conductor it is.	________
…our textbook says that all objects in the same room will eventually reach the same temperature.	________
…we measured the temperature of the wooden table and the chair leg and they were both 23°C even though the metal chair leg feels colder. If the metal chair leg was actually colder it would have been a lower temperature when we compared it to the temperature of the table.	________

Fig. 9.13 An example of an ASRT item

inquiry process. This work, however, will require new approaches that examine the structural, conceptual, epistemic, and social aspects of argument generation in a more synergistic fashion rather than looking at each of these aspects independently. Second, the review of the available literature suggests that much research on argument in science education has thus far focused on the identification of patterns and themes in students' arguments (e.g., "students tend to produce arguments that lack sufficient justification" or "students tend to produce arguments that have a simplistic structure") rather than focusing on the underlying reasons for these patterns. Studies that explore the causes of these patterns and themes will prove valuable in developing new curricular materials, instructional approaches, and technology-enhanced learning environments to promote and support more productive argumentation inside the classroom.

Clark and Sampson (2008) also developed the *Argumentation in Science Rating Task (ASRT)* in order to assess the criteria used by students for evaluating the quality of arguments and the quality of challenges to arguments. The ASRT consists of six items, three that focus on the quality of argument that can be used to justify a claim and three that focus on the quality of a challenge to an argument. For each item, individuals are asked to rank six arguments or six challenges to an argument in terms of quality. An example of an ASRT item is shown in Fig. 9.13.

TELS Research on Collaborative Argumentation

Much of the work in TELS adopts the view of dialogical argumentation as a process where "different perspectives are being examined and the purpose is to reach agreement on acceptable claims or course of actions" (Driver et al., 2000, p. 291). Much of this work therefore views dialogical argumentation as a social and collaborative process that is employed "to solve problems and advance knowledge" (Duschl & Osborne, 2002, p. 41) rather to "justify or refute a particular standpoint" (van Eemeren, Grootendorst, & Henkemans, 2002, p. 38). This view of argumentation emphasizes collaboration over competition and suggests that activities that promote dialogical argumentation can enable individuals to use each others' ideas to construct and negotiate a shared understanding of a particular phenomenon in light of existing data and new evidence (Abell, Anderson, & Chezem, 2000; Andriessen, Baker, & Suthers, 2003; Boulter & Gilbert, 1995; deVries, Lund, & Baker, 2002; Veerman, 2003). Thus, in practice, TELS work conceptualizes dialogical argumentation as a process of proposing, supporting, evaluating, and refining ideas to make sense of complex or ill-defined problems or phenomena. In the following sections, we provide an overview of studies investigating optimal grouping and seeding of online discussions for argumentation, the relative affordances and processes involved in collaborative versus individual engagement in argument construction, and the development and consideration of approaches for analyzing argumentation.

Optimal Grouping and Seeding of Online Discussions for Argumentation

The design of many online learning environments can be thought of in terms of "scripts" that orchestrate and control students' interactions with each other and the environments (Hesse, 2007; King, 2007; Weinberger, Stegmann, Fischer, & Mandl, 2007). One particular class of scripts focuses on grouping students together with other students who have expressed differing perspectives or stances. This general scripting approach can be referred to as a "conflict schema" (Dillenbourg & Jermann, 2007, p. 292). Yet, there are many ways to group students under the broad category of a "conflict schema" and there is little research available that explicitly examines the efficacy of different approaches.

Questions. How can the grouping of students for argumentation be informed by the content of their ideas? How should these discussions be seeded with initial ideas?

Context. This research investigated the efficacy of a conflict schema approach and also on optimal approaches to seeding the resulting online discussions with initial comments for discussion (Clark, 2004; Clark, D'Angelo, & Menekse, 2009; Clark & Sampson, 2005, 2007, 2008; Cuthbert, Clark, & Linn, 2002). The context of the research study was the *Thermodynamics: Probing Your Surroundings* project discussed earlier in this chapter. The version of the project for this research included eight activities. During the first five activities, students make predictions and collect real time data about the temperatures of objects found inside the classroom and explore interactive simulations dealing with such ideas as heat transfer, thermal conductivity, and thermal sensation. The sixth activity then scaffolds students in creating an explanation to explain patterns they notice within the data they have collected. This step involves a series of pull-down menus with sentence fragments (Fig. 9.14). The software underlying this interface then sorts the students into discussion groups in a manner determined by the researchers for each research condition. The seventh activity engages students in discussions where they critique a set of provided explanations, outline evidence for and against each explanation,

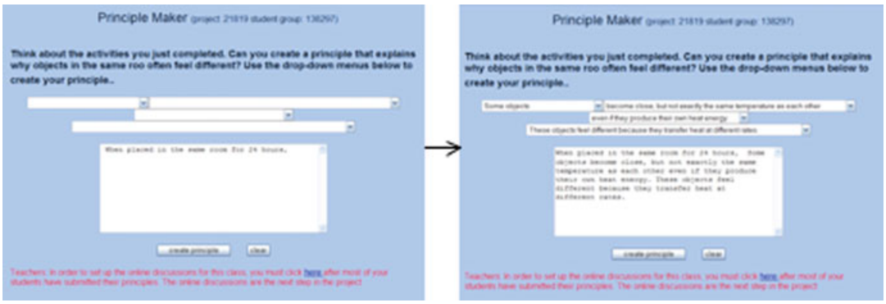

Fig. 9.14 Interface providing pull-down menus of sentence fragments that students use to construct their explanations for patterns they notice in the data

and engage in collaborative argumentation to work toward consensus. The nature of these provided initial explanations also varies by research condition. The eighth activity then allows students to construct a revised explanation after the discussions and to reflect on how their ideas have changed.

Methods. Some early studies did not compare across conditions and instead simply focused on the nature of learning supported within the discussion environment using various approaches to grouping students and to choosing the initial explanations to be discussed. Later studies involved random assignment of students to conditions within any given classroom in the study. Conditions in each study varied the nature of how students were grouped with one another and the nature of the initial explanations that they discussed in their online forum. Sample sizes for any given study generally included approximately 100 students. Studies were conducted in diverse public middle school and high school classrooms in California and Arizona.

Findings. Early work measured the structural quality of argumentation and participation in the ensuing discussion showed that the original personally seeded script that (1) sorted students into groups with students who had created explanations that were different from their own and (2) inserted the students' own explanations as the starting seed comments for the discussions was superior to standard online discussions that involved (1) no preexploration of the explanation fragments that constitute the preset explanations, (2) random group assignment, and (3) preset explanations as seeds (Clark, 2004; Clark & Sampson, 2005; Cuthbert et al., 2002). Subsequent research (Clark & Sampson, 2007) elaborated on these findings showing that carefully structured online environments integrating the personally seeded discussion approach can effectively scaffold high quality scientific argumentation in the classroom as measured from a structural perspective, particularly in light of the low levels of argumentation that typically take place within classrooms.

The research then proceeded to extend beyond structural perspectives in terms of students' discourse moves to also consider students' use of grounds and the conceptual quality of students' contributions (Clark & Sampson, 2008). This work suggested that personally seeded discussions are an effective way to encourage students to justify their ideas and challenge the ideas of others as indicated by students' use of grounds and rebuttals. This work also suggested strong interrelationships between structural quality, grounds use, and conceptual quality.

The next series of studies compared the contributions of the conflict-schema aspect of the script (which involved having the software sort students into groups purposefully with students who had created different explanations) versus simply randomly sorting students into groups. This series of studies also investigated the multiple approaches regarding the nature of the initial seed comments in the discussions. Pilot work for this series underscored how closely the various components of a pedagogical model hinge upon one another (Clark, Schleigh, Menekse, D'Angelo, & Sampson, 2008) and also suggested that students in discussions with their own comments participated more but also contributed more comments involving social pressure for others to "pick" their explanations and not those of others. These findings were reinforced by a subsequent study (Clark, D'Angelo, & Menekse, 2009). Comparisons between the trials in terms of modified gain scores in Clark, D'Angelo, & Menekse (2009) also showed that students in the conflict schema condition (where the software grouped students with other students who had created different explanations) outperformed students in the nonconflict schema trials (where students were assigned to partners randomly). In terms of conditions regarding the nature of the initial seed comments, students in the augmented-preset condition (where initial comments were preselected to represent an optimized range of possible student conceptions) demonstrate significant gains on their explanations compared to students in the personally seeded conditions (where the students' own explanations were included as the initial seed comments). This was true overall but particularly strong when combined with the conflict schema approach to group creation. Furthermore, the actual discussions of the students in the augmented-preset groups generally demonstrate the same or better overall argumentation quality in terms of structure, discourse moves, and grounds quality. Their participation levels were slightly lower, but the overall outcomes favored the augmented-preset condition in terms of the discussions themselves.

One hypothesis explaining the advantages of the augmented-preset performance is that the sets of seed comments for the personally seeded groups (which were their own explanations) often did not include the same diversity of ideas as the sets of preset seed comments in the augmented-preset groups. The average standard deviation for the sets of seed comment scores in the augmented-preset groups was higher than the average standard deviation of the seed comment scores in the personally seeded groups. This hypothesis was supported by the fact that the augmented-preset groups (1) showed a higher average gain and normalized gain than the personally seeded groups and also (2) included a higher proportion of group members who improved their scores than the personally seeded groups. The augmented-preset condition thus potentially results in more productive learning than the personally seeded condition by exposing students to a wider range of ideas on average. Another possible explanation is that students in the augmented-preset condition are guaranteed to have a fully normative explanation as one of the seed comments in their group while students in the personally seeded condition have their own explanations as seed comments for their group and thus may or may not have a fully normative explanation included depending on their group.

Implications. This series of studies suggests that supporting productive argumentation in online discussions is greatly facilitated by attention to group composition and to the initial structuring of the discussions in terms of their initial seed comments. In particular, the conflict schema approach to purposefully organizing students into groups with other students who have expressed different perspectives on the topic is valuable. The work also suggests that optimizing a range of initial seed-comments in terms of potential student perspectives is ultimately more valuable than including the students' own initial explanations even though the latter approach results in potentially higher levels of engagement.

Collaborative Versus Individual Argument Construction and Argumentation

Many researchers (Abell, Anderson, & Chezem, 2000; Bell & Linn, 2000; Kuhn & Reiser, 2005; McNeill, Lizotte, Krajcik, & Marx, 2006; Schwarz & Glassner, 2003) have encouraged students to work in collaborative groups when they engage in scientific argumentation. The work of these authors suggests that opportunities to collaborate with others can lead to more productive scientific argumentation and improved learning outcomes because groups can pool knowledge and take advantage of different cognitive or monitoring resources. Few studies, however, have explicitly compared individual and group performance on tasks that require students to engage in argumentation or examined the benefits of collaboration during an episode of argumentation for individual learning in the context of science education. Given this gap in the literature, the overall objectives of this study were (a) to evaluate the benefits of collaboration on argumentation outcomes and for individual learning and (b) to identify potential reasons for variation in group-level performance.

Questions. Do students who engage in argumentation in groups craft better arguments and learn more than students who engage in argument construction on their own? Do individuals adopt and internalize the group outcome? What are the characteristics of high versus low performing groups as they engage in collaborative argumentation?

Context. This research was conducted as a foundation for a proposed WISE project that did not ultimately reach completion focusing on issues of conductivity. Participants were asked to complete a complex task that required them to engage in argumentation in order to make sense of a discrepant event. This task, which is called the *ice melting blocks problem*, required them to determine which explanation, of six plausible alternatives, was the most valid or acceptable way to explain why ice placed on an aluminum block melts faster than ice placed on a plastic block even though the aluminum block feels much colder. Once the participants had determined which explanation was the best way to make sense of the phenomenon, they were asked to create a written argument that articulated and justified this explanation with appropriate evidence and reasoning. This study took place in a large suburban public high school located in the southwest United States.

Methods. The 168 participants in this study, who were enrolled in five different sections of chemistry at the same high school, were randomly assigned (within each classroom using a matched-pairs design) to one of two conditions to complete this task. Students assigned to the individual argumentation condition completed this task alone, while students assigned to the collaborative argumentation condition worked in a same-gender group of three (triads). In order to assess student understanding of the phenomenon in question, all of the participants were asked to complete the *ice melting blocks problem* for a second time. For this administration of the problem, each student was required to generate his or her own written argument for the *ice melting blocks problem*. To assess the participants' ability to apply what they have learned in a different context, individuals completed a conceptually identical task, the *why do objects feel different problem*. This problem was used because the discrepant event in this problem has the same underlying cause as the ice melting blocks problem. As before, these tasks required each student to produce a written argument that articulates and justifies an explanation for the event in question.

An in-depth qualitative analysis of the argumentation that took place within two more successful triads and two less successful triads was also conducted in order to identify major contrasting dimensions in group interaction that can be linked to differences in group outcomes. The four groups were selected based on differences in the quality of their written solutions to the *ice melting blocks problem* and because their interactions seemed representative of the kinds of interactions that took place in the more and less successful groups.

Findings. The results of this study indicate that, although groups of students did not produce substantially better products than the students who worked alone, students in the collaborative condition performed better on the mastery and application problems with moderate effect sizes. There was also a great deal of variation in the quality of the arguments produced by the triads. The qualitative analysis of the two more and two less successful groups suggests that the numbers of ideas students introduce into a discussion, how individuals respond to these ideas, the willingness of participants to challenge the ideas of others, the criteria individuals use to distinguish between ideas, and how students use data as they work seemed to influence on the overall quality of their final argument.

Implications. These findings indicate that collaboration was beneficial for individual learning but not for initial performance on the task. This result was unexpected given the extensive literature that suggests that collaborative effort can and should result in a product that exceeds what is possible by an individual working alone (Andriessen et al., 2003; Mason, 1998; Rochelle, 1992; Scardamalia & Bereiter, 1994). It seems that the ability to engage in productive argumentation with others is not something that comes easily to many students. These findings also suggest that students may need to learn how to engage in argumentation with others in a more productive way before individuals can reap all of the potential benefits of collaboration. Finally, the five differences in the ways more and less successful groups engaged in collaborative argumentation will help lay the groundwork for future studies that examine how individuals and their interactions influence group understanding and outcomes and why some groups are so much more productive than others.

Analyzing Argumentation

In addition to research on supporting argumentation, TELS also supported the development of a framework for analyzing argumentation (Clark & Sampson, 2005, 2007, 2008) and a review of approaches to analyzing argumentation (Clark, Sampson, Weinberger, & Erkens, 2007). Essentially, the framework developed by Clark and

Sampson focuses on the relationships between levels of opposition found within a discourse episode, the types of comments student make, the grounds quality included in those comments, and the conceptual quality of their ideas. By focusing on the relationships between these aspects of argumentation, the framework offers researchers a specific analytic tool to examine possible connections between argumentation and subject matter learning. Analysis grounds and conceptual quality is supported by flowcharts involving a series of binary decisions on the part of the coder to increase reliability of coding (Fig. 9.15). Clark and Sampson (2008) provide the most detailed account of the framework, including these flowcharts, detailed explanation of episode segmenting protocol, and many other issues, including description of the Cochran–Mantel–Haenzel χ^2 analyses based on table scores to determine the significance of the relationship between the *discourse move* of a comment and the *grounds quality* or *conceptual quality* of that comment. Jeong, Clark, Sampson, and Mushin (2011) explore the potential of expanding analysis with the framework by incorporating sequential analysis.

The review by Clark, Sampson, Weinberger, and Erkens (2007) examines five categories of analytic frameworks for measuring participant interactions within these environments focusing on (1) formal argumentation structure, (2) conceptual quality, (3) nature and function of contributions within the dialogue, (4) epistemic nature of reasoning, and (5) argumentation sequences and interaction patterns.

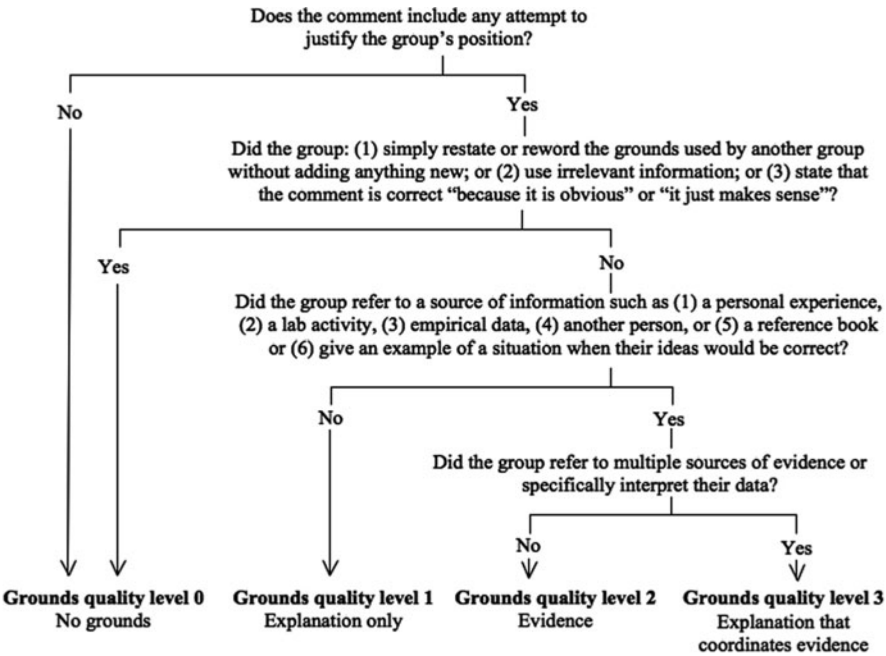

Fig. 9.15 Flowchart for analyzing grounds

Reviewed frameworks include Toulmin (1958), Erduran, Simon, and Osborne (2004), Clark and Sampson (2008), Kuhn and Udell (2003), deVries, Lund, and Baker (2002), Janssen, Erkens, Jaspers, and Kanselaar (2006), Baker, Andriessen, Lund, van Amelsvoort, and Quignard (2007), Jiménez-Aleixandre, Rodríguez, and Duschl (2000), Duschl (2008), Leitão (2000), Hogan, Nastasi, and Pressley (2000), Baker (2003), and Weinberger and Fischer (2006). The review highlights the diversity of theoretical perspectives represented in approaches to analyzing argumentation, the importance of clearly specifying theoretical and environmental commitments throughout the process of developing or adopting an analytic framework, and the role of analytic frameworks in the development of learning environments for argumentation.

Discussion: Implications for the KI Framework and Next Steps

As outlined in the Introduction to this chapter the design of projects in TELS was guided by the KI framework (Linn & Eylon, 2006). We now discuss the implications and next steps of the research described above for the four components of the KI framework as approaches for supporting learning: (1) eliciting current ideas, (2) introducing new idea, (3) developing criteria for evaluating criteria, and (4) sorting and reorganizing ideas.

Eliciting Current Ideas

Constructivist perspectives on learning assert that students learn by building upon their existing ideas. Some researchers (Inhelder & Piaget, 1969; Strike & Posner, 1985) suggest that eliciting students' current ideas helps them identify contradictions between their current ideas and the phenomena under investigation. Other researchers suggest that eliciting students' ideas supports students in building or refining connections to these ideas across contexts (Bransford, Brown, & Cocking, 1999; Linn & Hsi, 2000; Collins, Brown, & Holum, 1991; Brown & Campione, 1994). This high level goal of eliciting students' current ideas can be pursued through multiple avenues. TELS work on critique, argument construction, and argumentation provides insight into several of these avenues.

Structured Concept Maps. Research suggests that making connections between ideas explicit through concept maps can help students reflect on them. Structuring concept maps into domain-specific areas makes existing and missing connections within and across domains explicit. The spatial arrangement of concepts into domain-specific areas can indicate students' ontologies. Making connections between ideas visually explicit can be beneficial for collaborative learning. Concept maps can make changes in students' connections between ideas explicit. Expressing ideas and their connections into visuo-spatial forms can support students' reflection on their repertoire of ideas.

Asthma Module. A key theme of community science instruction is that learning materials build upon students' prior knowledge about science and the community. To elicit these ideas, the Asthma module and assessments prompt students to express their ideas about science and their personal world. The design of the decision justification assessment items prompted students to predict and iteratively refine their reasons and evidence in support of a particular intervention. Research reports that students significantly changed their explanations and justifications throughout their study of the Asthma module. This suggests that students not only expressed and reviewed their initial ideas and connections, but they were able to see how their understanding about the problem transformed over time.

Critiquing Virtual Experiments. TELS research on critiquing a fictitious student's (Mary's) virtual experiments (Chang, 2009; Chang & Linn, 2011) elicited students' idea and reflection on what counts a good experiment. The critique activity guided students to examine Mary's research question, method, and conclusions, consistent with critique activities proposed in other design principle research (Linn & Hsi, 2000; Linn & Eylon, 2006). Moreover, Mary's virtual experiment modeled the process of conducting experiments with a visualization. Modeling the process may help students who are confused by the visualization make sense of it (Betrancourt, 2005; Lowe, 2003, 2004). After critiquing Mary's experiment students had a clearer understanding of the visualization than they did in the other treatments without critique, as indicated by student performances on the embedded assessments.

Introducing New Ideas

A central goal of science education involves introducing new ideas to students. While most students manage to add ideas introduced during instruction, they face significant challenges in integrating these ideas to each other and to their prior knowledge (Clark, 2006). Traditional approaches to science instruction, such as lecture and textbook-based exercises, introduce ideas in ways that result in brittle decontextualized knowledge that is difficult to apply effectively (AAAS, 1993; Bjork, 1994; Bransford et al., 1999; NRC, 1996). Instruction that builds on students' normative ideas as well as their misconceptions can help students to add ideas that build from their prior understandings and promote durable and relevant scientific knowledge (Clement, 1993; Linn & Eylon, 2006). Effective science instruction should introduce new ideas in ways that allow students to generate connections among them. Although multiple approaches can be effective, specific approaches must be selected at the appropriate level of complexity (Feynman, Leighton, & Sands, 1995). TELS research on critique, argument construction, and argumentation has made contributions in clarifying several such approaches.

Seeded Discussions. Research on seeded discussions suggests that grouping students with other students who expressed different ideas than their own is more effective when the group is provided an optimized range of ideas that includes the scientifically normative idea than when only including the students' own ideas.

This may be because the range of ideas is optimized to represent a broad range of common misconceptions or because it is guaranteed to include the scientifically normative ideas. Future research will further explore and clarify the optimal ways to introduce new ideas in group contexts.

Asthma Module. The Asthma study presents results related to students' understanding of asthma as a community problem. The improved KI scores on the asthma explanation item from pre- to posttest demonstrate that students acquired ideas from the Asthma module, specifically the regional- or county-level community ideas. In addition, analysis of the embedded decision justifications provided evidence that the ideas contained in student responses often reflected the most immediate instruction. This study provides sufficient evidence that the Asthma module effectively added ideas to students' repertoire. Future design and research should focus on the develop criteria and sort ideas phases of the KI process.

Drawing and Critique. The drawing and critique study suggests how new ideas can be introduced through dynamic visualizations. In the HFC project, students first watched a video that shows the explosion of a hydrogen balloon. Then they interacted with a dynamic visualization demonstrating how chemical bonds change during hydrogen combustion. The visualization is built upon students' prior knowledge or experience. First, the representations of hydrogen and oxygen particles resemble the ball-and-stick physical models commonly used in science classrooms. Second, to relate to student personal experience about ignition (e.g., setting up a campfire), this visualization includes a "spark" button so that students can control how much energy is provided to ignite the reaction. Third, this visualization includes a dynamic temperature bar. Students can observe synchronous temperature change during the reaction and relate this to the explosion they observed in the video. With these features, the visualization introduced new ideas effectively and supported students to better integrate new ideas with prior experience.

Developing Criteria for Evaluating Ideas

Learners need to develop coherent ways to evaluate the scientific ideas they encounter as they add, refine, connect, promote, and demote ideas within their repertoires. Developing and understanding these criteria is not merely of philosophical or historical importance. Students maintain rich conceptual ecologies involving many prior ideas about many topics (Clark, 2006). As students encounter new ideas during instruction, a goal of science education involves helping them connect these new ideas in normative ways. Students must thus evaluate new and old ideas as they promote, demote, and refine ideas and connections between ideas. The criteria that students need to adopt in making these decisions normatively from the perspective of science as a discipline are not necessarily the ones that students bring with them from everyday life. While "compromising" and agreeing that "everyone is sort of right" may provide productive approaches for resolving social conflicts, for example, students need to understand the epistemological criteria of science if they are to engage productively in KI in science (Duschl & Osborne, 2002; Newton, Driver, &

Osborne, 1999; Keller, 1993; Longino, 1994). TELS research on critique, argument construction, and argumentation provides insight in terms of ways to support these goals.

Asthma Module. Students need several opportunities to develop and refine criteria for what counts as an effective community intervention to address their community's asthma problem. Students' low KI scores for the tradeoffs dimension suggest that students did not consider the positive and negative aspects of each program. Students may also need more instruction and practice constructing decision justifications that make explicit the criteria that inform their decision for which program will best address the asthma problem as they understand it.

Drawing and Critique. How can we encourage students to develop criteria to evaluate new and old ideas and to refine connections between ideas? The drawing and critique comparison study suggests two promising approaches. In the drawing approach, students need to evaluate among prior conceptions and new ideas they learned from the visualization to determine what to draw. In the critique activity, students need to evaluate among their knowledge and ideas represented in the given drawings to decide what to critique. This study provides evidence for the success of both approaches. It also suggests that by developing criteria to evaluate various ideas and conceptions, students are prompted to refine their knowledge and develop complicated links among ideas.

Structured Concept Maps. Research on structured concept mapping suggests that it can help students developing a wide range of criteria to critique connections between ideas. Structuring concept maps into different domain-specific areas makes connections within and across domains explicit, which fosters collaborative critique activities. Research suggests that critiquing existing connections might be easier for students with low prior knowledge as it provides them with starting points for their critical reasoning. Students with more prior knowledge might prefer creating their own concept maps which allows them to follow their own train of thought.

Critiquing Virtual Experiments. TELS research on critiquing virtual experiments encouraged students to develop criteria for virtual experiments when they distinguish ideas. This type of activity could promote metacognitive skills or metavisualization abilities by encouraging students to monitor their own reasoning (Gilbert, 2008; Hegarty 2004, 2005). For the experimentation items during the posttests, the critique group outperformed the other groups without critique activities, consistent with the argument that critique promoted developing criteria and distinguishing of ideas.

Sorting and Reorganizing Ideas

The fourth and final component of the KI framework builds on the first three by supporting students in developing, reorganizing, and refining connections among ideas. As part of this reorganization process, students apply their criteria to their new and preexisting ideas as they sort through potential contradictions, promote and demote ideas within their conceptual ecologies, revise and reprioritize connections between ideas, and identify situations where more information is needed (Bransford et al., 1999; Clark, 2001, 2006; diSessa, 1993; diSessa, Gillespie, & Esterly, 2004; diSessa & Wagner, 2005; Dufresne, Mestre, Thaden-Koch, Gerace, & Leonard, 2005; Linn & Hsi, 2000; Scardamalia & Bereiter, 1999). This process benefits from metacognitive skills and scaffolding to focus students' efforts most effectively (Bielaczyc, Pirolli, & Brown, 1995; Lin & Schwartz, 2003). Unfortunately, many students default to rote memorization (Songer & Linn, 1992), which results in brittle knowledge that is compartmentalized, difficult to apply or transfer, and quickly forgotten (AAAS, 1993; Bjork, 1994; Bransford et al., 1999; NRC, 1996). Students instead need significant support in engaging actively, consciously, and strategically in refining and restructuring their understandings (Clark, 2006). TELS research on critique, argument construction, and argumentation has also provided insights into these goals.

Seeded Discussions. The seeded discussions research focused primarily on this component of the KI framework. How can we encourage students to reflect on their ideas, compare these ideas to other ideas, and make informed decisions as they sort through evidence and arguments in terms of these ideas? This research suggests strongly the value of conflict schema approaches where students are grouped with other students who have expressed ideas different than their own to facilitate the sorting, evaluation, and reorganization of explanations and ideas for challenging science phenomena. Essentially, this approach "crowd sources" some of the cognitive load of integrating and contrasting ideas for the students while also potentially leveraging social motivations for engagement with the process.

Asthma Module. Students need more support linking different perspectives as they justify their decision about which community intervention to implement. Even though students' justifications included multiple perspectives, students struggled to connect the perspectives so they form a broad, integrated view of the asthma problem. Specifically, students isolated community and physiological perspectives. Since the module successfully adds ideas about physiology and the social implications of asthma, future revisions to the module should focus on the design of learning activities that promote connections among them. For example, students could role play and answer questions from a variety of assigned perspectives. This may prompt them to evaluate their existing ideas and generate connections they would not otherwise consider.

The research reported in the Asthma study also indicates that students struggled to demonstrate integrated evidence use. Analysis of the evidence use dimension revealed that the evidence presented in the Asthma module was added to students' repertoire, but not linked to reasons or other evidence. This finding was consistent across all communities, indicating that additional scaffolded instruction from the module and teacher would benefit a wide range of students. The revisions to the module should emphasize the develop criteria and sort ideas phases of knowledge integration. In particular, students need more explicit instruction on what constitutes an integrated explanation and decision justification and several opportunities to apply these criteria, such as the peer critique and the debate activities.

Structured Concept Maps. Research on structured concept mapping found that making the connections between domain-specific areas explicit can help students sorting out and reorganizing ideas. Concept maps constrain learners to decide on only one relationship between two concepts. This constraint requires students to apply criteria to select one connection and use supporting evidence when collaboratively working on a concept map. Research suggests that initial concept maps need refinement through critical revision. Presenting students with flawed concept maps can effectively support students' criteria generation and application. Findings show that students can apply criteria to their peers' work as well as their own work. Teacher-guided classroom discussions can support students' metacognitive understanding of different forms of criteria. Future research will extend critique-focused concept mapping to other science domains.

Critiquing Virtual Experiments. TELS research on critiquing virtual experiments engaged students in distinguishing their own ideas from those attributed to Mary. Neither the interaction condition nor the observation condition required students to distinguish among ideas (Chang, 2009; Chang & Linn, 2011). Observation and interaction may have encouraged adding ideas but not integrating ideas (Linn et al., 2004). In contrast, when students critique Mary's virtual experiment they need to sort and reorganize their and Mary's ideas in order to make a claim, link to the evidence, and provide arguments as they critique Mary's experiment.

Final Thoughts

The TELS research presented in this chapter represents a diverse set of science learning experiences that feature various scaffolding strategies, designed content, and supported modes of participation. Taken together, they strongly endorse the inclusion of critique and argumentation learning activities as an effective way to improve students' understanding of core science concepts. Furthermore, these research studies offer the field several analytic approaches to the assessment of science learning among a wide range of students.

While this chapter celebrates diversity in science education research, it also underscores the importance of a solid theoretical foundation. The KI framework guides the design and research of each study reported in this chapter as researchers work toward a collective goal—a deep, integrated understanding of science among learners. The principled approach of the KI framework affords designers and researchers flexibility in implementation and focus. This supports the creation of varied projects that are not limited or repetitive in their format, and also promote the high level of cumulative learning demonstrated in TELS overarching studies across multiple projects (Linn et al., 2006).

Consistent with the framework's emphasis on connections, each study reports on how students linked their prior and new ideas to the science content, their peers' dialogue, or information about their community. For example, the Space Colony study supports students' use of critique to promote connections between key genetic and evolutionary ideas. The Heat and Temperature study demonstrates how critique can guide students' identification of valid experiments, a key scientific process. Studies also promoted science learning in the form of engagement in professional and personal scientific practices. The HFC Cars study shows that students can be supported to use visualizations to inform their scientific understanding more effectively when they engage in critique. Related to argumentation, the Asthma study discusses how scaffolding the use of evidence and the consideration of tradeoffs can enhance students' engagement in integrated decision-making about community science. Finally, seeded discussion identifies scaffolding strategies that foster substantiated dialogue, a skill set that can be applied to numerous, relevant topics through learners' lifetimes.

These studies not only highlight successful approaches for engaging students in critique and argumentation, they also highlight room for improving these approaches. This creates fertile ground for continued research that focuses on the implementation and investigation of critique and argumentation as tools to promote deep science learning. In addition, these studies demonstrate how a shared overarching conceptual framework can encourage the integration of creative and diverse approaches to design, assessment, and analytic ideas from multiple theoretical perspectives, which in turn has contributed to an increasingly powerful and expansive database of design principles (Kali, 2006; Kali & Linn, 2008; Kali, Linn, & Roseman, 2008) for leveraging the KI framework to promote deep, complex science learning.

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