Technology-Enhanced Support Strategies for Inquiry Learning

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ABSTRACT

Design studies provide evidence for the effectiveness of specific supports for learning in technology-enhanced environments and suggest guidelines for the design and use of such features. The Design Principles Database is a public collaborative knowledge-building tool that helps capture and synthesize this knowledge using “design principles” as a basic construct. In this chapter, we highlight eight pragmatic design principles
from the Design Principles Database that are most likely to support learning, and we provide evidence that shows how learning is supported by features in technologies that apply these principles. We discuss the advantages and limitations of design principles to guide a design process and suggest that, for design principles to be more effective for guiding new innovations, they should be complemented with a design patterns approach.

KEYWORDS

Design principles: Research-based guidelines for instructional design; design principles can be articulated at different grain-sizes: specific principles characterize rationales for designing specific features in a learning environment, pragmatic principles connect rationales behind several features, and meta-principles synthesize a cluster of pragmatic principles.

Knowledge integration: The process of adding, distinguishing, organizing, and evaluating accounts of phenomena, situations, and abstractions.

Learning environment: A system that incorporates a set of features including a navigation system; learning environments can deliver curricula in any topic area.

Software features: Specific applications of technology intended to advance learning; features include designed artifacts such as modeling tools, simulations, micro-worlds, visualizations, collaboration tools, reflection prompts, games, and embedded assessments.

INTRODUCTION

This paper synthesizes the benefits of technology-enhanced supports for inquiry learning and is intended to help designers build on past work and help researchers report new findings in the context of current work. To achieve these goals, we take advantage of efforts to collate design principles, such as those devised by Brown (1992), Kali (2006), Kali (in press), Merrill (2002), Quintana et al. (2004), Reigeluth (1999), and van den Akker (1999). We draw on current views of inquiry, we synthesize findings from design research. Design researchers conduct iterative refinements to develop successful innovations (Bell et al., 2004; Design-Based Research Collective, 2003; Simon, 1999; Kari, 2000; Barron et al., 2000; Fishman et al., 2004; University instruction primarily relies on web delivery of information (Herrington et al., 2005, p. 757). Mioduser and colleagues (1999) summarized the current uses of technology in education as: “One step ahead for the technology, two steps back for the pedagogy.”

To identify promising elements of supports for inquiry, we synthesize findings from design research. Design researchers conduct iterative refinements to develop successful innovations (Bell et al., 2004; Design-Based Research Collective, 2003; Simon,
Studies comparing alternative designs or sequences of refinements provide evidence for the effectiveness of specific supports, shed light on the mechanism behind supports, and suggest guidelines for implementation. These studies often summarize findings in design principles, learning principles, patterns, and related synthesis methods to capture both the innovations and the mechanisms that govern their success. Brown (1992) offered learning principles to synthesize her research findings. Collins (1992) called for guidelines to capture research-based practical design knowledge. These efforts echo practices in other design-based fields that have found principles helpful, including architecture (Alexander et al., 1977), graphical communication (Tufte, 1983), and computer science (Gamma et al., 1995).

The current synthesis starts with features of inquiry innovations captured by Kali (2006) and Kali (in press) in the Design Principles Database (http://www.design-principles.org). The current entries in the Design Principles Database represent the contributions of over 50 individual researchers. The database includes more than 70 features (mainly from physical, life, and earth sciences.) The database connects: (1) descriptions of promising features, (2) the rationale for the feature, and (3) evidence for the impact of the feature to pragmatic design principles. Pragmatic principles are abstracted guidelines that connect similar rationales behind features in different learning environments. Although features are entered in the database as independent entities, they are often parts of sequences of features that comprise a learning environment.

The database is organized around meta-principles. Meta-principles are overarching ideas that synthesize a cluster of pragmatic principles. The meta-principles in the database include make thinking visible, make science accessible, help learners learn from each other, and promote autonomous lifelong learning.

The structure of the Design Principles Database emerged from longitudinal research on technology-enhanced science learning (Linn and Hsi, 2000; Linn et al., 2004b). The Computer as Learning Partner research program identified the 4 meta-principles and the first 14 pragmatic principles in their 20-year-long effort to iteratively refine effective interactive science experiences (Linn and Hsi, 2000). The Design Principles Database has grown with contributions from participants in workshops, from course activities, and from the public (Kali et al., 2002). It serves as a collaborative knowledge building tool for communities who design and explore educational technologies (Kali, 2006). The Design Principles Database enables designers to explain the pedagogical rationales behind each feature in a learning environment and for community members to respond and add their experiences. It is based on the idea that explaining the rationale of a feature can be useful for other designers. Researchers have added additional principles (Linn et al., 2004b) and applied the ideas to design of assessments (Clark and Linn, 2003), professional development (Williams and Linn, 2003), and learning environments (Linn et al., 2003). Researchers can explore the application of principles in new contexts and add their findings back to the Design Principles Database. The design knowledge grows as principles are debated, refined, or warranted with additional field-based evidence.

**SUPPORTS FOR INQUIRY LEARNING**

To synthesize supports for inquiry learning, we start with the four meta-principles in the Design Principles Database and select pragmatic principles that connect with the largest number of software features. We have highlighted two promising features for each pragmatic principle. The features vary in their grain size; some represent whole learning environments (such as Model-It), some represent tools in a learning environment (such as the inquiry map in WISE), and others represent elements in software (such as the manipulative animated three-dimensional illustrations in Geo3D). Table 12.1 shows the features and their connections with pragmatic and meta-principles. We describe the meta-principles, associated pragmatic principles, and illustrative features to characterize supports for inquiry learning.

**Meta-Principle: Make Science Accessible**

Designers seek to make science accessible for learners to elicit the full repertoire of ideas. They create supports that increase the relevance of science for all learners—those aspiring to careers in science and those taking their last science course. These supports respond to the common complaint that science is not relevant or useful. They also remedy the often inadequate images of science held by students (Hofer and Pintrich, 2002). Two pragmatic principles that follow this meta-principle call for communicating the diversity of science inquiry and for connecting to personally relevant examples.

**Pragmatic Principle: Communicate the Diversity of Science Inquiry**

This principle calls on designers to expose learners to the rich diversity of the inquiry process. Far too often students leave science class with an image of inquiry
TABLE 12.1
Features Described in This Chapter and Their Connections to Pragmatic and Meta-Principles

<table>
<thead>
<tr>
<th>Pragmatic Principles</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Meta-Principle: Make Science Accessible</strong></td>
<td></td>
</tr>
<tr>
<td>Communicate the diversity of science inquiry</td>
<td>Inquiry map in WISE</td>
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<tr>
<td>Connect to personally relevant examples</td>
<td>SenseMaker in WISE</td>
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<tr>
<td><strong>Meta-Principle: Make Thinking Visible</strong></td>
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<tr>
<td>Provide students with templates to organize ideas</td>
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<tr>
<td>Provide knowledge representation tools</td>
<td>Design rule of thumb template in SMILE</td>
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<tr>
<td>Enable three-dimensional manipulation</td>
<td>Model-It</td>
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<td><strong>Meta-Principle: Help Learners Learn from Each Other</strong></td>
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<tr>
<td>Encourage learners to learn from others</td>
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<td><strong>Meta-Principle: Promote Autonomous Lifelong Learning</strong></td>
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<td>Enable manipulation of factors in models and simulation</td>
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</table>

as dogmatic and inflexible or abstract and incomprehensible (Linn et al., 2004a). Technology-enhanced learning environments can help students become aware of the diversity of science inquiry by engaging students in a variety of inquiry processes. We exemplify how this principle is applied in two different features that are part of the Web-Based Inquiry Science Environment (WISE) (Slotta, 2004).

Inquiry Map in WISE

To help students explore inquiry processes, WISE uses an inquiry map, which is a dynamic-graphic guide shown in each of the WISE projects (Figure 12.1). It graphically represents the steps of the inquiry in the project. This enables students to get an overview of the project and the inquiry strategies it includes. The inquiry map also expands and collapses each project into its

Figure 12.1 WISE inquiry map (in middle) with index of activities (left) and reelection note (right).
main inquiry components. Teachers using WISE indicate that the map makes students more independent in their inquiry activities, thus strengthening their understanding of the diversity of inquiry processes. In many cases, the inquiry map provides answers to “What do I do now?” questions, making the inquiry process more self-directed. The map also helps students get a better understanding of how each step in the project relates to the whole inquiry process (Linn and Hsi, 2000).

**SenseMaker in WISE**

Another feature that communicates the idea of diversity in science inquiry engages students in controversial scientific debates (Bell, 2004). The WISE SenseMaker tool (Figure 12.2) helps students figure out the relationships that exist between different web resources. As they investigate pieces of web-based evidence, students organize the items into categories in SenseMaker. This sorting of pieces of evidence helps students consolidate their own stance about the controversy and prepare for a class debate. During the debate, the graphical representations of student arguments are displayed. Students can see the diversity of inquiry strategies by comparing their arguments to those of other students and of experts (Bell, 2004). SenseMaker can support debates about such issues as the threat of malaria. Students explore the ethical trade-offs between protecting human life (by spraying DDT) and protecting wildlife and the environment (by banning the use of DDT) (Seethaler and Linn, 2004). Research shows that engaging students in such debates and supporting their inquiry process with SenseMaker can help students develop a more integrated understanding of complex science topics (Bell, 2004).

**Pragmatic Principle: Connect to Personally Relevant Examples**

Personally relevant problems, such as determining how to keep a drink cold, make science accessible because they elicit intuitive ideas to fuel inquiry (Linn and Hsi, 2000; Songer and Linn, 1991). Linn et al. (2004b) showed that eliciting the broad range of student ideas about science and engaging these ideas enables students to build more coherent, durable scientific views. This principle advocates using personally relevant examples as contexts for scientific inquiry. The examples below show how this principle was applied by two research groups.

**Authentic Contexts in the Jasper Project**

The Jasper project, using the anchored instruction approach (Cognition and Technology Group at Vanderbilt, 1990, 1997), was one of the earliest large endeav-
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ors to use technology to anchor instruction in authentic contexts. Jasper includes a set of 12 video-based adventures that focus on mathematical problem solving. Each video ends in a complex challenge. The adventures are designed like good detective novels, and all the data necessary to solve the adventure are embedded in the story. The Jasper adventures present a believable story that has interesting characters, a complex and important challenge, and extensions to a variety of curricular areas. To solve the challenge, the students combine problem-solving skills, mathematics concepts, and the information in the video. The adventures were designed to bridge the gap between everyday and school problems. They provide a common context for instruction, an authentic task, and a chance to see that school knowledge can be used to solve real problems.

**Contextualized Definitions in TELS Modules**

The Technology Enhanced Learning in Science (TELS) *Hanging with Friends, Velocity Style!* module (Tate, 2005) embeds scientific terms in the context of an interview with a teenager. The purpose of the interview is to find the teenager’s velocity, but the context of the interview is her trip from Lake Park to the movie theatre to meet her friends. The interviewee speaks in everyday language while communicating the information needed to determine her velocity, saying, for example, “I was running a bit late and almost didn’t get a seat. I arrived at the movie theatre at 5:05 p.m. This is referred to as my final time.” The discourse blends everyday language and events (being late to a movie) with information needed to determine velocity. By bringing everyday events (a conversation or interview) into play, the feature draws students into the activity and helps them place it in a familiar context. They compute the velocity of each friend to see if all will arrive in time. The feature motivates students to understand the specific terms and data needed to compute velocity for an everyday event.

**Meta-Principle: Make Thinking Visible**

To promote inquiry, designers often encourage students and teachers to make their thinking visible. When students make thinking visible, they can inspect their own knowledge integration processes and deliberately guide their learning (Bransford et al., 1999; Collins et al., 1991; Linn, 1995). To support these processes, designers create tools that students use to map their ideas and externalize their thoughts at different stages of the learning process. Designers also use models or visualizations embedded in inquiry projects to make complex concepts and scientific phenomena visible. We highlight three pragmatic principles that follow this meta-principle. The first two are intended to help students make their own thinking visible, and the third is intended to make complex scientific phenomena visible. We exemplify each pragmatic principle with two features from different contexts.

**Provide Students with Templates To Organize Ideas**

To support students in articulating complex scientific ideas, designers have created what might be called templates. Templates scaffold students in representing their ideas and revising them as they complete complex activities (Kolodner et al., 2004). Below are two examples that show software features from two contexts that apply this principle.

**Principle Maker in WISE**

One feature that exemplifies how templates can help organize ideas, is the Principle Maker (Clark and Sampson, 2007). The Principle Maker (Figure 12.3) is a tool in the WISE environment that helps students synthesize data that they have collected or experienced into a principle. By providing building-block phrases, the tool scaffolds the task and gives students clear
alternatives without dictating ideas. The Principle Maker is part of a TELS project called Thermodynamics: Probing Your Surroundings. Research conducted by Clark and Sampson (2007) suggests that scaffolding students in the creation of principles helps make student ideas explicit. Clark and Sampson take advantage of the principles students build to set up discussions that include groups with opposing ideas. They argue that this process promotes dialogical argumentation, a feature found under the meta-principle of “learn from each other.” By making thinking visible the Principle Maker enables a more sophisticated form of argumentation than is found in typical science classrooms. As a result, students have a good sense of the views of their peers and can spend their time supporting, evaluating, and critiquing ideas.

Design Rule of Thumb Template in SMILE

Another feature designed according to this principle is part of the Learning by Design classrooms, and the Supporting Multiuser Interactive Learning Environment (SMILE) (Kolodner et al., 2004). This feature assists students in generating and revising design rules of thumb throughout a project experience. Design rules of thumb are lessons that are learned from experience. The template includes constructs that help students construct a design rule of thumb in the following format: When/If (describe the action, design, or choice you are working within) use/connect/build/employ/measure (list your suggestion or method) because (list or supply the evidence or science principle or concept that backs up your suggestion) (Figure 12.4). Students initially attempt to generate these rules of thumb in small groups based on their experimental results or on cases they are reading. They discuss the rules of thumb as a class and revise them. Ideally, students notice ideas they cannot explain and identify the science they need to learn. Research shows that, before use of the template, students were often unable to make the appropriate connections to science. When templates were used in the context of a class, teachers were better able to introduce the appropriate scientific concepts. When the teacher helped students create rules of thumb as a class before using the software, students using the software created better rules of thumb (with a richer situation description and justification) than students who did not have the template available in the software (Kolodner et al., 2004). This principle calls for providing learners with tools with which they can visually represent, at different learning stages, their understanding of scientific ideas. Linn et al. (2004b) claim that knowledge representation tools can promote interpretation and theorizing about evidence.
Pragmatic Principle: Provide Knowledge Representation Tools

Model-It
An example of a tool that enables students to represent and test their knowledge is Model-It, developed at the University of Michigan. Model-It is a learner-centered tool for building dynamic, qualitative-based models. Model-It was designed to support students, even those with only very basic mathematical skills, in building dynamic models of scientific phenomena and running simulations with their models to verify and analyze the results (Jackson et al., 2000). For example, students can build models of water quality and then test how various pollutants would affect water quality. Model-It provides an easy-to-use visual structure with which students can plan, build, and test their models (Figure 12.5). Model-It has been used with thousands of students and their teachers in both urban and suburban areas. Research shows that when properly integrated into the curriculum, Model-It allows students to take part in a variety of scientific practices such as testing, debugging, building relationships, specifying variables, and synthesis (Jackson et al., 2000).

Causal Mapper
Another example of a feature that enables students to represent their understanding is Causal Mapper. This feature, developed by Baumgartner (2004), is a stand-alone application that allows learners to make sense of a set of causal relationships. Causal mapping refers to the use of directed node and link graphs—similar to concept maps, in some ways—to represent a set of causal relationships within a system. The causal map shown in Figure 12.6, for example, reflects the representation by two sixth-grade girls of the factors that contribute to the health of a stream. Causal mapping is more structured than concept mapping, in that links capture causal relations. Students can develop a shared representation for causality, and groups can quickly examine and critique each other’s causal maps and discuss complex causal chains. Baumgartner (2004) showed that, when students map their own data using Causal Mapper, they develop their ability to interpret their data and use it as evidence for their investigations.

Pragmatic Principle: Enable Three-Dimensional Manipulation
In the earlier description of the “make thinking visible” meta-principle, we mentioned that one aspect is animating complex scientific phenomena. “Enable three-dimensional manipulation” is a pragmatic principle that emphasizes making scientific phenomena visible. Many students have difficulty perceiving three-dimensional (3D) structures, which are presented in textbooks as two-dimensional (2D) representations. Technology can provide tools that enable students to manipulate representations of these structures. Visualizations can enable students to rotate objects being studied and thus view them from various directions (Dori et al., 2003; Hsi et al., 1997; Kali et al., 1997). Other types of 3D visualizations can also improve understanding, as described in the following two features:
Three-Dimensional Illustrations in Geo3D

Geo3D was designed to respond to the spatial abilities required in structural geology and the difficulties that high-school students have in the perception of geological structures (Kali and Orion, 1996). In Geo3D, students can visually bisect illustrations of geological structures (see Figure 12.7). They explore relationships between observable and unseen properties of the geological structures. These relationships strengthen the perceptions of geological structures created by folding, uplifting, and erosion (Kali et al., 1997). Even short interactions with these animations (1 to 2 hours) improves students’ skills in the visualization of geological structures.

Scaffolds To Support Student Use of Molecular Modeling Software

Many students have difficulties relating symbolic representation of molecules to 2D and 3D models, especially when organic compounds are involved. Dori et al. (2003) and Barak and Dori (2005) designed a suite of activities that takes advantage of molecular modeling software originally designed for experts, such as WebLab Viewer and ISIS/Draw. To use software designed for experts, learning materials must highlight the salient information for students (Edelson et al., 1999). Guided by this suite of activities, students construct 2D representations of chemical substances using ISIS/Draw, and then use WebLab to transform the 2D
representations into a 3D image (framework, ball-and-stick, or space-filling) (Figure 12.8). Students compare their representations to those of their peers. Dori et al. (2006) showed that these activities increase students’ understanding of the physical and chemical properties of simple and complex compounds.

Meta-Principle: Help Learners Learn from Each Other

To help students develop criteria and distinguish among ideas, designers embed social supports in inquiry activities. These opportunities encourage students to listen and learn from others and take advantage of the collective knowledge in the classroom community. Encouraging students to analyze and build on ideas from peers can introduce new perspectives and motivate students to form criteria (Scardamalia and Bereiter, 1994). Additionally, when students interact, they bring to light the alternative views held by learners and the criteria used to interpret ideas (Bransford et al., 1999). We highlight one pragmatic principle that follows this meta-principle and describe two features that show its use in different contexts.

Pragmatic Principle: Encourage Learners To Learn from Others

This principle emphasizes helping learners to listen and learn from others. When students explain their thoughts to other students, they sort out their own ideas and learn new ideas from others. Students can help their peers understand an idea by articulating concepts using familiar vocabulary and relevant examples.

Automated Gathering of Peer-Evaluation Outcomes in CeLS

One example of this principle involves automating peer evaluation. CeLS (Collaborative e-Learning Structures; http://www.mycels.net) allows instructors to construct online structured collaborative activities, including peer evaluation. CeLS automatically gathers and analyzes information submitted by students and shows it in various customizable forms. Figure 12.9 shows an example of the type of information that can be presented in a peer evaluation activity designed in CeLS, including statistical analysis, a histogram, and a collection of student justifications for their grading (presented anonymously). Kali and Ronen (2005) used a peer-evaluation activity designed with CeLS in a philosophy of education course. Undergraduate students constructed a conceptual model of their “ideal school” and developed more sophisticated epistemologies as a result of peer evaluation.

Supports for Collaboration in eStep

Another example of technology supports that encourage learners to learn from others is the eStep system (Hmelo-Silver et al., 2005; Derry et al., 2005). In eStep, learners read and view a case study that presents a classroom dilemma. They individually reflect on the dilemma and propose an initial solution. Then they...
collaborate with other learners to collectively arrive at a revised solution. The lesson ends with individual critiques of the group solution and reflection on the learning, collaboration, lesson design, and usefulness of the solution to their own professional practice. Derry et al. (2005) reported that eStep produced significant increases in teacher and learner abilities to think deeply about student understanding and that the course was more effective at producing transfer than a traditional lecture-based approach covering the same material.

**Meta-Principle: Promote Autonomous Lifelong Learning**

To become lifelong learners, students need supports that help them guide their own learning, recognize new ideas, and develop a view of effective inquiry. They need to engage in sustained project work so they can connect personally relevant problems to class topics and reflect on experience using a robust inquiry process in diverse contexts (Linn et al., 2004b). Students benefit from learning to monitor their progress. To encourage autonomy, designers scaffold comprehensive inquiry processes that students can apply to varied problems, both in class and throughout their lives, to explore ways to ensure that these practices are internalized. We present two pragmatic principles from the Design Principles Database that apply this meta-principle and exemplify each, with two features.

**Pragmatic Principle: Enable Manipulation of Factors in Models and Simulations**

Interactive models, simulations, and visualizations support autonomy but often frustrate learners because they are too complex or too sophisticated (Hegarty et al., 1999). To enable students to benefit from models, simulations, and visualizations, designers guide interactions and seek ways to promote autonomy. Models, simulations, and visualizations enable learners to connect everyday, microscopic, and symbolic representations of phenomena. They can be used in virtual labs when it is impossible, dangerous, difficult, expensive, or unethical (in the case of animal studies) to conduct a hands-on experiment. They can illustrate many fields, such as finance, mathematics, physics, meteorology, biology, or social sciences. Shternberg and Yerushalmy (2003) distinguished between models that illustrate concepts (such as the relationship between a function and its derivative) and models of physical phenomena such as chemical reactions. In both types, students need strategies for exploring how the model behaves under varied conditions. Many computer-based models allow learners to explore the effect of each variable in a system by holding others constant. Oftentimes, instructional materials help learners internalize the strategies appropriate for exploring complex models and simulations. For example, students need skill in identifying extreme situations and exploring limitations of models.

Figure 12.9 Peer evaluation activity designed with CeLS.
Students also need to connect computer simulations to hands-on experiments. Ways to guide students to explore inquiry strategies for models and simulations are exemplified in the following features.

**Models of Molecules in Molecular Workbench**
The Molecular Workbench software allows designers to create dynamic visualizations to illustrate scientific ideas (Pallant and Tinker, 2004). Students can manipulate visualizations that link atomic level models with observable phenomena to conceptualize events such as the production of greenhouse gases. An understanding of atomic level interactions is essential to most of modern science. The idea that many macroscopic phenomena emerge from large numbers of simple interactions is both simple and profound. For example, the example model shown in Figure 12.10 enables students to view how their manipulation of the temperature and the mole fraction of various substances changes the speed of movement of the particles, and the reactions between them. To promote autonomy, Molecular Workbench visualizations have an intuitive interface. Typical students using Molecular Workbench demonstrate large gains in understanding of atomic and molecular level interactions, reasoning about atoms and molecules, and transfer to understanding of new problems (http://www.concord.org).

**Modeling Derivatives**
To help students develop a qualitative understanding of the relationship between a function and its derivative, even before they are taught the formality of mathematics, Shternberg and Yerushalmy (2002) developed the function and derivative model (Figure 12.11) as part of the Visual Math project (http://www.cet.ac.il/math/function/english/). The model allows comparison of two views: a function view at the top and a derivative view at the bottom. Using a set of seven graphical icons, learners can build their own function. As they build and manipulate the function, they view how the derivative changes. This model can be used for student-initiated problems or as part of the activities in the Visual Math curriculum.

**Pragmatic Principle: Encourage Reflection**
A well-established method for promoting lifelong learning is to encourage learners to reflect on their own learning and generate explanations. Linn and Hsi (2000) found that, when learners reflect, they monitor their progress and reach new insights. The pattern of conducting an exploration and then reflecting improves understanding (Davis, 2006). Combining an experiment, investigation, or research endeavor with reflection can improve both activities. In contrast to text materials, technology-enhanced materials can prompt students to reflect and capture student ideas while they are learning. Finding the appropriate amount and type of reflection requires iterative design and depends heavily on the context. Designing prompts that elicit reflection is challenging. Some prompts just lead students to conclude that they were successful (Davis and Linn, 2000). The examples below show how this principle helps teachers and learners.

**Prompts for Reflection on Action in CASES**
Prompts for reflection are a part of a teachers’ online journal tool in CASES (Davis, 2006). They appear as sentence starters or questions listed on the left side of the journal. Two to six prompts are listed under each of three different categories: thinking about today, planning ahead, and general thoughts. A teacher selects a prompt from the left column and the prompts appear in the journal. The prompts are designed to elicit infor-
information that may otherwise remain tacit, such as justifications for curricular decisions. This reflection on action influences student learning outcomes by helping teachers to think critically about their lessons and teaching methods and to make more effective decisions in real time in the classroom (Davis and Krajcik, 2005).

**Note-Taking in WISE**

The WISE environment allows designers to embed notes and students to view them at any time. Prompts direct students to explain their ideas, make connections, or make predictions (see Figure 12.1). Slotta (2004) showed that reflection notes can help students monitor their own learning.

**DISCUSSION AND CONCLUSIONS**

In summary, to identify promising supports for inquiry learning we took advantage of a community resource—the Design Principles Database. We organized the discussion around the meta-principles to capture essential elements of effective instruction. To illustrate the meta-principles, we selected the pragmatic principles that connected to the largest number of features. We provided evidence for the pragmatic principles by describing research on illustrative features. These features communicate the complexity of inquiry instruction as well as the insights emerging in recent research programs.

These results, other findings in the Design Principles Database, and related research all provide strong support for the four meta-principles. First, effective supports for inquiry make science accessible by connecting to the interests or ideas held by the learner (Krajcik et al., 1998; Linn and Hsi, 2000). When students grapple with everyday examples, they can evaluate their intuitive ideas and distinguish them from normative views. Second, effective supports make thinking about scientific phenomena visible to teachers and learners by animating, visualizing, articulating, or representing complex phenomena in multiple ways (Linn, Lee, Tinker, Husic, and Chiu, 2006). Modern technologies offer a window on unseen scientific phenomena, combined with supports that enable interpretation of these events. Third, effective supports help students learn from each other by asking students to explain their ideas and to critique the ideas of others (Davis, 2006). When students discuss their ideas, they can develop criteria to distinguish them. Fourth, effec-
tive supports promote autonomy by stimulating learners to monitor their progress and reflect on their learning (White and Frederiksen, 1998). When students evaluate their own ideas, they can learn to think critically about their progress.

As these examples reveal, designers of inquiry environments have created powerful features that can give new designers a head start on building effective inquiry instruction. The value of the full set of meta-principles is also reflected in the connections among the features in the Design Principles Database and in the characteristics of learning environments that include multiple features. Features are linked to the pragmatic-principle that they illustrate but some features also have elements that connect to other pragmatic-principles. For example, the features that enable three-dimensional manipulation of scientific phenomena also have elements that promote autonomy by asking students to reflect on their observations. Learning environments such as WISE and Model-It typically include features that connect to all four meta-principles; for example, WISE includes SenseMaker, Principle Maker, online discussions, and reflection notes. Evidence in the Design Principles Database suggests that it is reasonable to conclude that effective supports for inquiry should take advantage of all four meta-principles.

Another way to evaluate the features is to examine how they support the process of knowledge integration described in the introduction. The features in the Design Principles Database support one or more of the four processes of knowledge integration: eliciting ideas, adding ideas, developing criteria, and sorting out ideas. Features such as collaborative brainstorming or reflections on everyday phenomena elicit student ideas. Features such as representations or animations of scientific phenomena add new ideas to those held by the learner. Features such as peer evaluation or SenseMaker encourage students to develop criteria for distinguishing among ideas. Features such as Causal Mapper or prompts for reflection encourage learners to sort out their ideas. These connections between features and the processes of knowledge integration prompted the development of design patterns that describe promising combinations of features (Linn, 2006; Linn and Eylon, 2006).

A design pattern is a sequence of activities followed by teachers and students in a classroom. Linn and Eylon (2006) synthesized a broad range of research on inquiry science to identify patterns that employ the four knowledge integration processes in productive ways. These four processes play out in ten design patterns that research has shown to promote knowledge integration; for example, the pattern using modeling or simulation to enable knowledge integration starts by eliciting predictions about an observable phenomenon such as heating water. The pattern then adds ideas using a feature such as Molecular Workbench. Next, the pattern might guide learners to form conjectures and compare them using a feature such as Principle Maker. Finally, the pattern might help learners consolidate ideas with a feature such as note taking. We are currently linking design principles and design patterns.

The Design Principles Database is effective when it is built into a structured design process and used in a social context, such as a graduate course or a workshop (Kali et al., 2006). Participants in such courses found that the design principles approach assisted them in brainstorming ideas for activities, in generating alternatives, and in designing specific activities; however, they found that the Design Principles Database did not provide sufficient guidance for putting these activities together to create learning environments.

Design patterns can help with this dilemma by suggesting sequences of activities. The Design Principles Database helps when designers seek ways to implement the activities in the sequence. By testing and refining these resources for designers and by adding additional resources that capture the experiences of designers, the field can become more cumulative.

The Design Principles Database is a work in progress. As more designers add their features, new pragmatic principles may emerge, and existing principles may need revisions. The Design Principles Database can help the field become more cumulative by capturing the interplay between the learning context and the design guidelines. Many instructional designers use the analyze, design, develop, implement, and evaluate (ADDIE) framework to create and test innovations (Dick et al., 2001). Those committed to design research acknowledge the importance of the iterative refinement process, in which designs are tested multiple times (Barab and Squire, 2004; Bell et al., 2004; Collins et al., 2004; Design-Based Research Collective, 2003). Both approaches yield results that can be added to the database. In addition, we continue to sponsor opportunities to add and refine features and principles. These activities will elaborate and improve our understanding of supports for inquiry learning.

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HISTORY

Early in 2005, Phil Harris, Executive Director of the Association of Educational Communications and Technology, approached Mike Spector and asked if he would like to lead the development of the third edition of the Handbook of Research on Educational Communications and Technology. Spector consulted with Dave Jonassen, editor of the previous two editions, and with Lane Akers, Editorial Vice President for Lawrence Erlbaum Associates. A strategy was then developed to make the third edition more international in terms of scope and contributions and to have an editorial team rather than an individual editor lead the effort. Spector, Harris, Akers, and Jonassen then discussed who might comprise that editorial team. By May 2005, the editorial team of Mike Spector, Dave Merrill, Jeroen van Merriënboer, and Marcy Driscoll was formed.

The strategy developed to determine the contents had four major steps: (1) extended conversations with Jonassen to take lessons learned from the first two editions into this edition; (2) a survey of AECT members to get their reactions to the second edition and recommendations for the third edition; (3) presentations at the annual meetings of AECT in 2005 and again in 2006 to get direct feedback from AECT members about plans for the third edition; and (4) ongoing discussions among the editors via teleconference, videoconference, and occasional face-to-face meetings about the Handbook.

Nearly 200 persons responded to the Handbook survey, which asked about general use, individual chapters in the second edition, and their desires for the third edition. Responses indicated that the Handbook is used primarily by doctoral students initiating a research review for their dissertation studies, by faculty as an additional resource for teaching courses on related topics, and by researchers seeking a quick review on a specific topic. Recommendations for the third edition included addressing more topics and having shorter chapters with more references to recent research. We followed these recommendations to the best of our ability.

At the 2005 AECT meeting, the editorial team developed the basic organization of the Handbook around four parts: (1) Strategies, (2) Technologies, (3) Models, and (4) Design and Development. These parts reflect major aspects involved in deploying information and communications technologies (ICT) for educational purposes; they are preceded by a Foundations part and followed by a Research Methodologies part. Each part was led by one of the coeditors with assistance from a second coeditor and several external reviewers.

Also at that meeting, the editorial team with significant input from Jonassen developed an initial list of desired contributors. The agreement with our publisher, Lawrence Erlbaum Associates, was that the second edition would remain available online through the AECT website to AECT members, so some excellent chapters in that edition were not included in this third edition. Author guidelines were developed that reflected the outcomes of the survey and the organizational framework developed by the editorial team. Specifically, we asked for shorter chapters with longer bibliographies, and we also requested keywords with definitions to be included in a glossary and an indication (via asterisks in the reference section) of core references.

A general call for contributions was issued to the AECT membership. The lead editor for each part of the Handbook was responsible for determining the contributing authors to that part and for coordinating drafts and reviews of that part of the Handbook. In short, the editorial team functioned as a team, with coeditors having and taking responsibility for the various parts of this Handbook.

We made a conscious effort from the very beginning to include many more non-American contributors. Rather than simply ask those who had contributed to the first two editions to again make a contribution, we determined that we ought to think ahead to the fourth edition. As a consequence, when we eventually approached authors, we expressed a preference for pairing a highly experienced author with a promising young scholar who conceivably could lead a contribution in the next edition. The intent in selecting authors was to ensure that chapters would be broadly representative of the relevant research in a particular area rather than reflecting only one view or approach.

The Handbook took shape in late 2005. At that time, we had as many as 100 chapters targeted for development. The editorial team narrowed that list to about 65 in early 2006 when development of individual...
As already noted, the third edition is divided into six parts. Part I, Foundations, led by Marcy Driscoll, is expected to remain fairly stable over the years and require only minor updating every five years or so. The Foundations part includes historical, theoretical, and methodological foundations and perspectives. This initial part of the Handbook is aimed at the various sets of assumptions that underlie research in educational communications and technology. Some of these assumptions are based on what has gone before. Others are based on developments in other disciplines. The goal in this part of the Handbook is to make these assumptions explicit, summarize key developments, and provide pointers to exemplary work that has implications for research in educational communications and technology.

Part II, led by Dave Merrill, is focused on strategies. The various chapters in the Strategies part cover both instructional and learning strategies, although the emphasis is on implications for design and development. These various strategies can be linked with subsequent chapters in Parts III, IV, and V of the Handbook, in accordance with our organizational framework.

Part III, led by Mike Spector, is focused on technologies. The editorial team collectively decided that the distinction between hard and soft technologies was too facile and not especially meaningful, and it was dropped in this edition. The Technologies part of the Handbook consists of 17 chapters on both digital and non-electronic technologies, intelligent and non-intelligent technologies, and planning and evaluation technologies, as well as technologies for implementation.

Part IV, led by Jeroen van Merriënboer, focuses on models. Issues concerned with various types of and approaches to learning are discussed. These models clearly inform design and development and can be linked to various instructional strategies covered in Part II. The Models part includes general models directed toward learning in schools as well as outside schools and models that focus on learning in specific domains such as medicine, science, and reading.

Part V, led by Dave Merrill, focuses on design and development. This part of the Handbook discusses research that pertains directly to professional practice. Readers will find chapters on familiar topics such as competency development, task analysis, change agency, and performance assessment. The Design and Development part also covers innovative treatments of design languages, design and development teams, and user-centered design and development.

Part VI, led by Jeroen van Merriënboer, focuses on methodological issues. This part follows the empirical cycle through theory development, experimental design, and data collection and analysis. Design sections adhere to the main parts of the Handbook and treat, in order, research on strategies, technologies, models, and design and development. For data collection, special requirements for (virtual) laboratories are discussed. Analysis methods include the analysis of learning processes, interactions, and complex performances. The Methodological Issues part ends with a discussion by the editorial team of a research agenda that should help our field to build a strong scientific foundation for the future.

The division into four core parts that represent key aspects of using information and communications technologies to support learning and instruction, preceded by a Foundations section and followed by a Methodological Issues section, is intended to facilitate use of this research handbook. We have intentionally kept titles brief and descriptive to help facilitate those who wish to follow a thread through the four core parts of the Handbook.

An example of a thread concerned with research on instructional modeling and representation might involve the chapters on representation strategies, modeling technologies, model-facilitated learning, and design languages. Many such threads are possible. Individual chapters were primarily developed to represent stand-alone treatments of specific topics within the framework and guidelines provided. All chapters have extensive lists of references that should prove useful to researchers new to a particular area of research and to doctoral students conducting their background research.
It is our belief that professional practitioners and educational researchers will benefit from the chapters in Parts I and VI. These chapters, as well as many others in the *Handbook*, are likely to be useful for those responsible for leading graduate seminars in the areas of educational technology, instructional systems, or learning environment design and development. It is our hope that this edition of the *Handbook* will be as useful as the previous two editions. Time will tell. In any case, we invite you to give us your feedback, which we will pass along to whoever is selected to lead the development of the fourth edition.

Learn, educate and persevere,

*Mike Spector, Dave Merrill,
Jeroen van Merriënboer, and Marcy Driscoll*