Software for Managing Complex Learning: Examples from an Educational Psychology Course

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Inquiry-based instruction including problem-, project-, and case-based methods often incorporate complex sets of learning activities. The numerous activitites run the risk of becoming disconnected in the minds of learners and teachers. STAR.Legacy is a software shell that can help designers organize learning activities into an inquiry cycle that is easy to understand and pedagogically sound. To ensure that classroom teachers can adapt the inquiry activities according to their local resources and needs, STAR.Legacy was built upon four types of design principles: learner centered, knowledge centered, assessment centered, and community centered. We describe how a STAR.Legacy constructed for an educational psychology course helped preservice teachers design and learn about effective inquiry-based instruction.

□ New developments in learning theory suggest that many teachers—the present authors included—can improve student learning by changing their teaching practices (e.g., Cognition and Technology Group at Vanderbilt [CTGV], 1996). As college teachers, we often find that our predominant method of teaching is to assign chapter readings and then to give lectures and demonstrations of points we think are important (see also, Nunn, 1996). We assess learning by asking students to answer multiple-choice questions, give presentations, or write essays that paraphrase and elaborate on what they have learned. These methods of teaching and assessment "work" in the sense that most students can demonstrate that they have learned something. Nevertheless, the quality of their learning is often less than satisfying. Reading assignments and follow-up lectures can produce evidence of learning that looks successful at first glance but misses many elements of understanding when analyzed in more detail (Bransford & Schwartz, in press; Schwartz & Bransford, 1998). Students, for example, often fail to use spontaneously what they have learned in a new setting despite the fact that it is highly relevant. Whitehead (1929) referred to the failure to apply learning as the "inert knowledge" problem. A number of studies show that traditional approaches to instruction often produce inert knowledge (e.g., Bereiter & Scardamalia, 1985; Bransford, Franks, Vye, & Sherwood, 1989; Gick & Holyoak, 1983; Perfetto, Bransford, & Franks, 1983).

Instructional innovations such as problem-based, case-based and project-based learning have been designed to combat the inert knowledge problem (for precise distinctions among these approaches see Barron et al., 1998; Williams, 1992). Instead of simply assigning fact-based readings or providing lectures, students begin their inquiry with challenging problems, and they learn information relevant to those challenges as the need arises. Instructional approaches that are organized around cases, problems and projects have been used for a number of years in professional schools for training in medicine (e.g., Barrows, 1985), business (e.g., Gragg, 1940), law (e.g., Williams, 1992), and educational administration (e.g., Bridges & Hallinger, 1995). These approaches to instruction are also being used with increasing frequency in K–12 education (e.g., Barron et al., 1998; CTGV, 1992; 1997; Krajcik, Blumenfeld, Marx, Bass, & Fredricks, 1998; Penner, Lehrer, & Schauble, 1998). Williams (1992) provides an excellent review of problem-based and case-based learning. Data on the effectiveness of these approaches for student learning are discussed in Barron et al. (1998; see also, CTGV, 1997; Hmelo, 1998; Michael, Klee, Bransford, & Warren, 1993; Vye et al., 1998).

There are risks associated with the use of case-based, problem-based and project-based learning. A major risk is that engagement can be mistaken for learning. For example, when completing a hands-on activity such as building a model rocket, students may be active and enthused, yet assessments of the systematic understanding may yield disappointing results (examples are discussed in Barron et al., 1998). Another risk comes from the assumption that these are constructivist activities that require teachers to eliminate traditional activities such as assigning fact-based readings or providing lectures. Assumptions such as these fail to differentiate constructivism as a theory of knowing from theories of pedagogy. Constructivist theories assume that people always use their prior knowledge to construct new knowledge even if they are sitting through a lecture (e.g., Cobb, 1994). Lectures are often not the best way to help novices learn because their knowledge is not sufficiently differentiated to understand a lecture at a deep level. However, if students are given opportunities to develop well-differentiated knowledge, lectures can be a powerful way to help students organize their knowledge and experiences (Schwartz & Bransford, 1998). There are times for lectures and readings, but they need to occur when students are prepared to appreciate the insights that they contain.

In our experiences, case-, problem- and project-based learning are most effective when teachers, students and other interested parties form *learning communities,* where there is individual accountability yet people collaborate in order to achieve important objectives, and where there is access to expertise that often lies outside the classroom community (e.g., Bransford et al., in press). Frequent opportunities for formatively assessing individual and group progress are also important for helping students achieve (e.g., Barron et al., 1998; Vye et al., 1998).

In this article we describe a software shell, STAR.Legacy, that is designed to guide attempts to help students learn from case-, problem-, and project-based learning. STAR.Legacy supports the integration of four types of learning environments that we believe are especially important for enhancing learning (CTGV, in press):

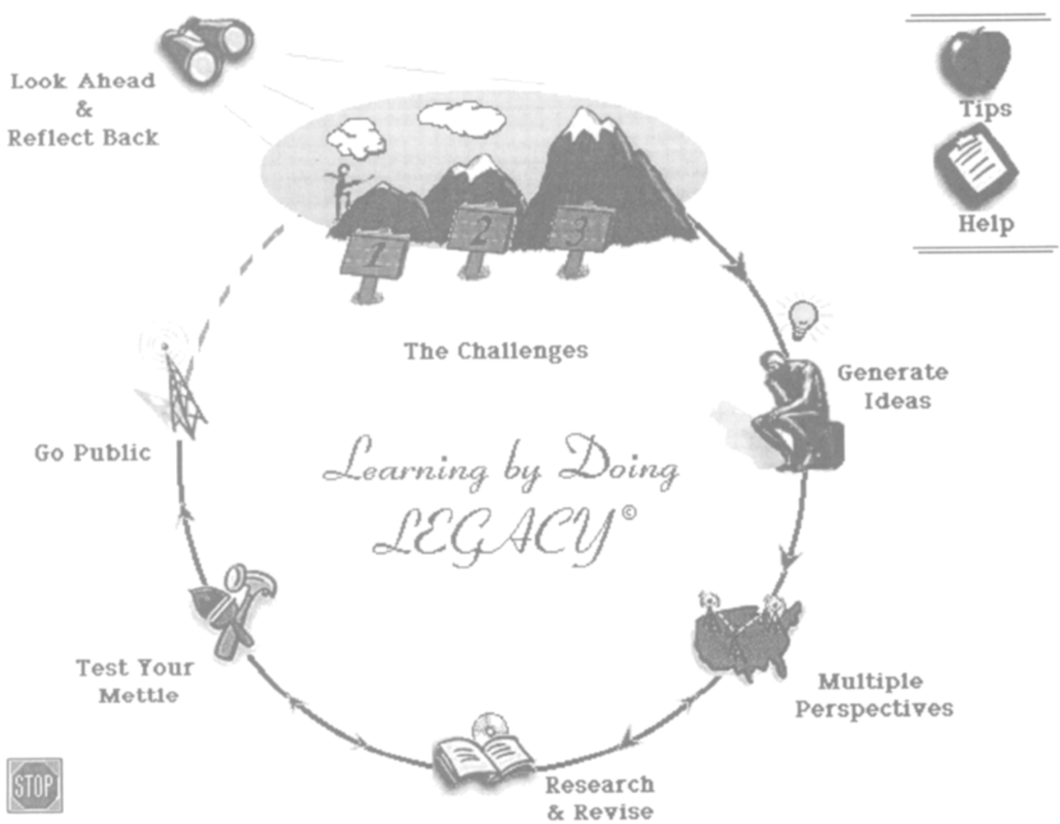
1. Learner-centered environments that focus on knowledge, skills and attitudes that students bring to the learning situation
2. Knowledge-centered environments that focus on knowledge that is organized around core concepts or big ideas that support subsequent learning in the disciplines (e.g., see Brown & Campione, 1994; CTGV, in press)
3. Assessment-centered environments that help students' thinking to become visible so that both they and their teachers can assess and revise their understanding
4. Community-centered environments that capitalize on local settings to create a sense of collaboration—both among students and with other members of the community

Integrating these four types of environments requires what we call *flexibly adaptive instructional design* (Schwartz, Lin, Brophy, & Bransford, in press). As teachers use problem-, project-, or case-based materials, they need to tailor learning activities to the unique qualities of their settings while maintaining a focus on core disciplinary knowledge. To adapt a curriculum (knowledge-centered) to their setting, teachers need to work with the prior knowledge, skills, and cultural resources that a specific group of students brings to a situation. To accomplish this, students need opportunities to bring their knowledge and beliefs to bear on school subjects (learner-centered), and teachers need frequent opportunities for assessing student progress toward knowledge standards (assessment-centered). And, because community is a powerful and variable property of learning settings, teachers should be given opportunities to maximize community resources to motivate and enable collaboration and achievement (community-centered).

STAR.Legacy promotes flexibly adaptive instructional design in two primary ways. It helps teachers *adapt* complex curricula by including a model of inquiry that draws attention to each of the learning environments within a single software shell and that provides a framework for making pedagogically sound modifications. It supports *flexibility* by including a suite of software tools that are simple to learn and use, and that make it easy to modify a given STAR.Legacy.

Figure 1 provides an overview of the STAR.Legacy inquiry model. This figure is a screen shot of the software's primary interface. The interface organizes student activity into typical phases of inquiry and helps make their learning processes visible to themselves and the teacher. By clicking on the different icons of the interface, the software branches to the corresponding "pages" of resources and activities. These pages provide opportunities for students to complete progressively complex challenges (the Challenge mountains in Figure 1), to generate their own ideas on how to meet the

Figure 1 ☐ STAR.Legacy "Home Page"



challenges (Generate Ideas), to compare their ideas to others and reflect on the differences (Multiple Perspectives), as well as to develop, assess, and revise their understanding (Research & Revise, Test Your Mettle) before they present their final solutions to each challenge (Go Public). To convey these multiple opportunities for learning, assessing, and making modifications, we use the name STAR, an acronym for software technology for action and reflection.

In addition to the explicit inquiry cycle, which guides decisions about adaptation, STAR.Legacy includes simple software tools for modifying the resources available in each phase of inquiry. Typically, teachers work with and modify a STAR.Legacy that has been filled with activities and resources designed for inquiry into a specific topic such as ecosystems or electrical circuits (see *Border Blues.Legacy* in Schwartz, Lin, et al., in press; and *DC.Legacy* in Schwartz, Biswas, et al., in press). STAR.Legacy makes it easy for teachers to add new resources, including texts; patches to other programs or websites; and video clips of themselves, their colleagues and their previous students. For example, video clips of colleagues commenting on various challenges might occur in the Multiple Perspectives part of the inquiry cycle. This allows teachers to introduce their students to a larger learning community; for example, to other professors on campus (or teachers in a school) who have expertise that is relevant to a particular course. STAR.Legacy also enables students to contribute to the learning environment. After developing sufficient understanding, students can leave a legacy for next year's students by adding their own insights or lessons (hence the name Legacy). This can be very motivating for students, and it helps curricula evolve so that they best fit local needs.

In the following sections we describe STAR.Legacy in more detail. We describe it in a context where it was used it in an attempt to improve our own practices as college professors. We developed a STAR.Legacy called Learning By Doing Legacy (LBD.Legacy). LBD.Legacy was designed to inform educational psychology students about problem- and project-based learning. Our objective was to help preservice teachers learn to design and adapt this type of instruction to the needs of their students and the resources of their community. One measure of whether we achieved these objectives comes from the legacies the students created to teach next year's students. Later in the article, we describe how students' legacies naturally incorporated many of the important pedagogical principles of STAR.Legacy as well as resources from the local community. Unfortunately, because LBD.Legacy was new to us and the students, we were not prepared to experimentally compare student learning and behavior in this context with learning in more traditional contexts. Nevertheless, our experiences and the legacies the students created provided informal data that are quite valuable and suggest research issues that are worthy of subsequent investigation. In the remainder of the article, we describe these observations in the process of detailing four aspects of STAR.Legacy:

1. The explicitness of the inquiry model
2. The components of a single learning cycle
3. The multiple learning cycles that help people progressively deepen their understanding
4. The importance of reflecting on the overall learning process and creating legacies for other people to use

We conclude with a discussion of the software tools that make STAR.Legacy flexible and the prospects for further development of flexibly adaptive instructional design.

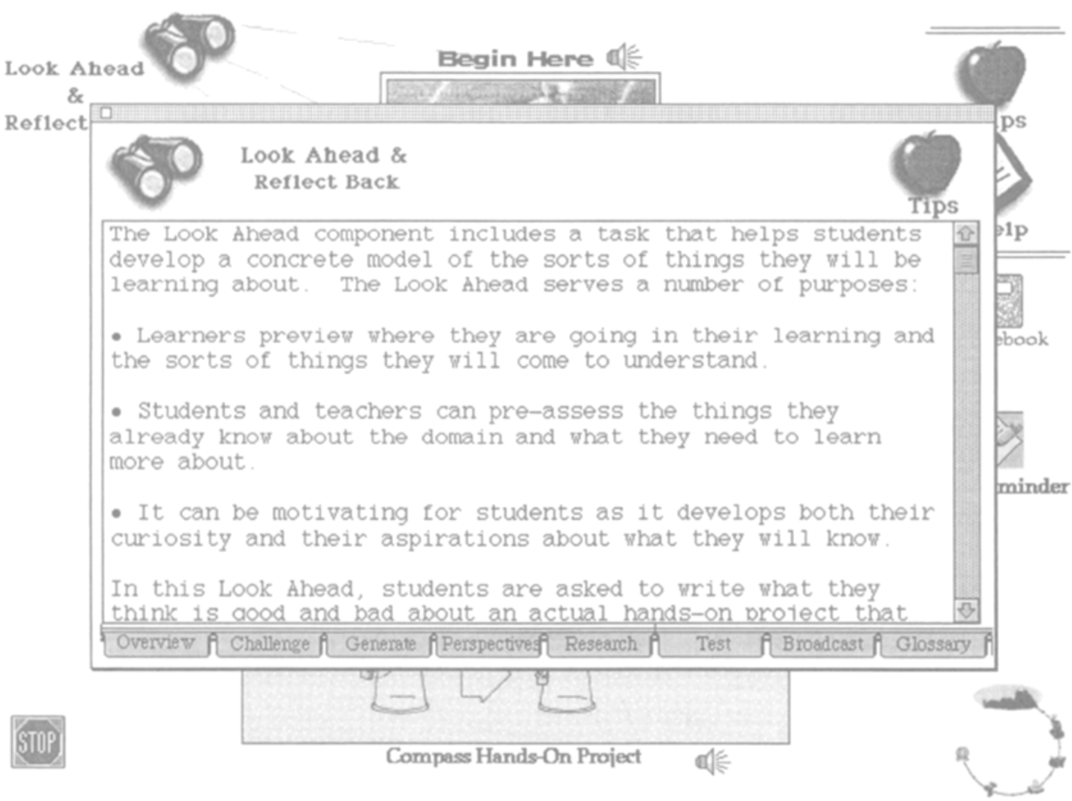
MAKING THE INQUIRY MODEL EXPLICIT

Every STAR.Legacy, including LBD.Legacy, uses the basic interface shown in Figure 1. The interface is meant to provide an explicit model for structuring inquiry in problem-, project-, and case-based learning. The model includes a number of components that we describe more fully below. For example, there is the Look-Ahead & Reflect Back component that students complete at the start and finish of any STAR.Legacy. There are the multiple Challenge mountains that students are encouraged to "climb" one after another to progressively deepen their expertise. And, there is the basic learning cycle that students complete as they engage in inquiry for each one of the multiple challenges of a STAR.Legacy.

These components offer one possible formalization of insights gathered through collaborations with teachers, trainers, curriculum designers, and researchers. The specific components of STAR.Legacy were chosen because they have repeatedly appeared as important, yet often implicit, components of learning and instruction—components such as continually making formative assessments of student progress, and continually illuminating ways for students to situate and think about a topic. Although STAR.Legacy tries to formalize these components, it is not intended to replace on-the-spot, expert decisions. Rather, it is meant to augment local expertise by helping teachers (and students) develop an understanding of learning events. Teachers and students, for example, may choose to jump around the learning cycle depending on their assessments of their current learning needs. To help people understand these options, context-sensitive "Tips" provide the rationale for a particular component of the inquiry model, along with suggestions for using the specific activities included with that component. Figure 2, for example, shows the explanation that appears when an individual clicks on the Tips apple on the Look-Ahead & Reflect Back page of LBD.Legacy. Hopefully, such explanations help people understand the point of an instructional design feature, and this understanding will, in turn, help them adapt instruction to their own ends.

The explicit inquiry model of STAR.Legacy has been in response to our observation that learning is enhanced when teachers and learners can "see where they are" in a complex sequence of inquiry. This became apparent during the implementation of an integrated model of instruction and assessment called SMART, an acronym for "Scientific and Mathematical Arenas for Refining Thinking" (Barron et al., 1998; CTGV, 1997). Using the SMART model, classrooms progress from problem-based learning that develops a solid knowledge foundation to

Figure 2 ☐ A Sample Tip for the Look Ahead-Reflect Back Page



more open-ended project-based learning. Within the model, there are many opportunities for students to generate their own ideas, consult knowledge resources, share thoughts, and assess and revise their understanding. By moving through cycles of learning and revision in the context of related problem and project challenges, students progressively deepen their understanding (Barron et al., 1998; Vye et al., 1998).

We knew from prior implementations of SMART that students (and teachers) often felt lost in the details of the specific activities (Barron et al., 1995). They did not know how particular activities fit together or how the activities would contribute to their overall understanding of the problem or their ability to complete the project. Students and teachers were at risk of viewing the curriculum as a "humongous compilation" of learning activities that were not particularly connected or dedicated to any larger goal. To avoid this, we started to post "SMART Maps" that students and teachers could consult to monitor learning (Vye et al., 1998). These precursors of the STAR.Legacy visualization showed how different learning activities joined to make a sequence that supported the ultimate goal of completing the final project. The explicit SMART Maps helped students. For example, because the activity allotted a time for revision, students learned that revision is a natural component of learning, rather than a punishment for not learning (Schwartz, Lin, et al., in press).

One of the goals of presenting an explicit inquiry model is to help teachers and students transfer inquiry practices from one topic to another because they can see similarities across the activities. For example, during the past year we have had the opportunity to introduce the STAR.Legacy framework to a number of K–12 inservice teachers who had been using various non-Legacy curriculum units, such as our problem-based Jasper Adventure and Scientists in Action series (for descriptions, see CTGV, 1997). We showed them how these units looked when placed in the STAR.Legacy framework. The response was extremely positive. Teachers felt that they could instantly "see" the implicit learning cycles common to much of their instruction. Moreover, the teachers found it easier to talk with team partners who teach other disciplines because they could see that their instructional techniques actually shared a common structure of inquiry.

TRAVERSING THE BASIC STAR.LEGACY CYCLE

In this section we traverse the elements of the STAR.Legacy cycle. We focus primarily on the LBD.Legacy that was designed to help preservice teachers understand the strengths, weaknesses, and different how-tos of problem-, project, and case-based approaches to instruction. The LBD.Legacy begins with a preview in Look Ahead (& Reflect Back). Afterwards, students meet their first inquiry challenge by clicking on the smallest mountain. To complete this challenge, they complete each of the components of the learning cycle. When done with the first challenge, students click on the second mountain to meet their second inquiry challenge. They again complete the learning cycle, using a new set of resources tailored to the second challenge. After completing the same process for the third challenge, students conclude LBD.Legacy by revisiting the Look Ahead & Reflect Back. In the following sections, we trace this sequence and describe those classroom observations that seem most promising for further research.

Look Ahead

The Look Ahead & Reflect Back is represented by the binoculars in the upper-left corner of the main interface (Figure 1). Students complete the Look Ahead before they meet any of the challenges. Clicking on the binocular icon brings students to a screen that is designed to help them preview the knowledge domain and develop learning goals.

Nearly all models of learning and instruction emphasize the importance of goal setting (e.g., Newell & Simon, 1972). Often, goals for learning are presented as specific objectives, primarily for the teacher's eyes. For educational psychology these might include, "students will list three reasons that problem-based learning improves transfer," "students will compare and contrast summative and formative assessment," and so forth. Many attempts to list specific objectives fall short of the ideal because they are frequently perceived as a discrete list of statements that often seem vague and unrelated. Our preference is to help teachers and students develop a more coherent and concrete model of the topic that they will learn about and the sorts of things they will be able to accomplish by completing their Legacy journey.

The Look Ahead & Reflect Back for LBD.Legacy begins with an audio narrator who explains that one of the benefits of expertise is the increased ability to notice significant events in the environment. As an example, the students are shown an eight-second, digitized video clip of a single play in a football game. Afterwards, they watch protocols of two women who were asked to recount what they had seen in the play. The first woman, a novice, states, "I'm so embarrassed. I think . . . I think the quarterback ran the football." The second, a relative expert, states, "OK, the defensive backs jumped offside during a blitz. The quarterback handed the ball to one of the running backs who broke two tackles and was on his way to a touchdown." The students then get a chance to watch the football play again to assess their own expertise. After this example, the narrator explains that LBD.Legacy will increase their ability to notice and understand important aspects of a type of instruction called *learning by doing,* in which students complete problems, projects, and hands-on activities. To get a sense of their own expertise in this domain, the narrator suggests that the students evaluate the provided example of a prototypical hands-on project that involves making a compass from magnets. The students do not spend their time studying this particular project in LBD.Legacy. The compass project simply offers a brief and relatively familiar example of an activity that falls under the rubric of learning by doing. The students' task is to notice what is good about the compass project and what could be improved and how.

Currently, we see five potential benefits to the Look Ahead. (a) It helps students to situate the upcoming lessons and learning goals in their prior knowledge, interests, and communities of practice. (b) It provides learners an opportunity to see their destination in a domain of knowledge and to see the sorts of things they will come to understand. (c) It helps develop a shared domain model that facilitates discourse and community within the classroom. (d) It offers a learner and teacher pre-assessment. As learners, students can identify what they need to learn more about. For teachers, this activity can occur at a classroom level so that teachers can appraise their class's initial domain knowledge. This can help teachers anticipate learning needs, as well as help them design and tailor their use of STAR.Legacy and other classroom resources. For example, with the LBD.Legacy Look Ahead, we were able to see that few of the education students saw anything wrong with an activity that provided no context for learning about compasses, and no information that explained why compasses work, or why they are useful. This indicated important gaps in the students' understanding of how to transform learning by doing into *doing with understanding.* (e) Finally, the Look Ahead can serve as a benchmark for reflection and self-assessment. In particular, after completing the learning cycles, students return to Reflect Back on what they have learned compared to their first try at the Look Ahead. As we document later, this can help students see how much they have learned.

The Challenges

After completing the Look Ahead, students are prepared to work on the STAR.Legacy challenges. To access the first challenge, students click on the smallest mountain. In LBD.Legacy, Challenge 1 asks students to generate and explain reasons why they might want people to learn by completing projects. To anchor their inquiry into this challenge, the students watch a clip of a movie that shows a high-school history teacher who is giving a stultifying lecture on the chronology of the Depression era (for a discussion of anchors, see Bransford, Sherwood, Hasselbring, Kinzer, & Williams, 1990; CTGV, 1994). Afterwards, a "narrator" in LBD.Legacy suggests that the students use this example of instruction as a foil to help them think about why projects can be a useful alternative. The remainder of the learning cycle prepares the students to complete this challenge. After completing the learning cycle and presenting their final answer to Challenge 1, the students repeat the process with Challenges 2 and 3 (described below).

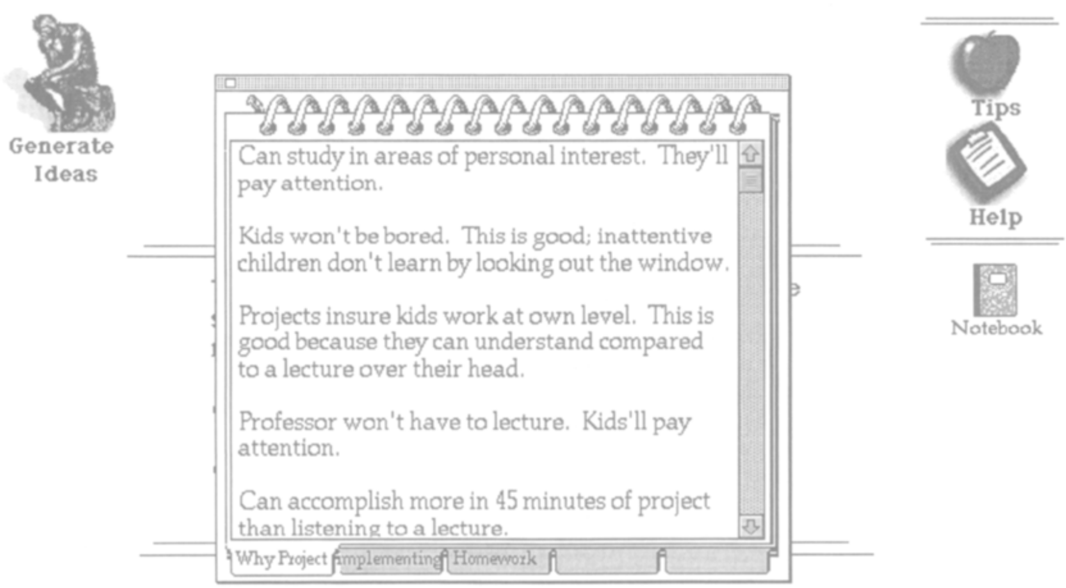
Generate Ideas

After students understand a challenge, they progress to Generate Ideas where they explicitly make their first attempt at generating issues and answers relevant to the challenge. Typically, the Generate Ideas page includes a text that reminds students of the challenge (e.g., justify project-based learning) and that instructs students to record their initial ideas. Figure 3 shows the ideas that one group of education students generated for Challenge 1 after watching the video clip of the excessively passive classroom. The students' thoughts were entered into an electronic notebook where they could be subsequently revised and improved upon.

In a computer-rich classroom, one way to use the notebook feature is to have each student generate ideas into a separate notebook. Alternatively, for the LBD.Legacy, the challenge was watched as a whole class, and students generated their initial ideas on paper. Afterwards, students offered their ideas in the whole-class context, and the teacher combined those ideas into the collective notebook shown in the figure. The notebook served as a focal point for further discussion of the generated ideas.

There are several reasons that Generate Ideas is an explicit component of the Legacy cycle. One is that it encourages students to share ideas; everyone has an opportunity to hear what others think. For the teacher, this complements the Look Ahead by providing a more specific assessment of what the students understand about the topic. For example, Figure 3 reveals that students primarily think about a project's benefits in terms of motivation. For the students,

Figure 3 ☐ The Class's Notebook Entries for the Generate Idea Phase of Challenge 1



it provides an opportunity to learn what other students think. Too frequently, students have no idea about their peers' knowledge. As a consequence, it becomes difficult for students to build community by taking advantage of knowledge distributed throughout a classroom.

A second reason to have students generate ideas is to make thinking explicit rather than allowing it to remain tacit and vague. The act of specifically recording their views about a topic helps students discover what they think and know. This awareness is facilitated when students contrast their ideas with other ideas. Appropriate contrasts, much like setting two wines side by side or seeing two ideas juxtaposed, can help students notice important distinctions they might otherwise overlook or dismiss (Bransford et al., 1989; Bransford & Nitsch, 1978; Gibson & Gibson, 1957; Schwartz & Bransford, 1998). For example, most instructors in the behavioral sciences have experienced the frustration of students' stating that a particular point is just "common sense," when in fact, the students would never have applied the common sense on their own. When students are asked first to generate ideas, they become more appreciative of the contrast between their initial observations and ensuing observations that they had originally overlooked. This appreciation can help them grasp what is new about ideas rather than merely assimilate them into old ideas and gloss over what is new and important.

Multiple Perspectives

Following the initial generation of ideas comes Multiple Perspectives. There are many situations where multiple perspectives are a natural component of learning (e.g., a conference panel, cooperative jigsaw groups, different voices in a novel). In STAR.Legacy, this important feature of learning is made explicit. For Challenge 1 of LBD.Legacy, students hear the ideas generated by four educational experts who also saw the video of the Depression-era lecture. These experts introduce students to vocabulary and perspectives that are quite different from their own and that characterize expert approaches to the topic. By focusing attention on contrasts between what the students generated and what the experts generated, students are helped to grasp the significance of new information and understand its relevance for helping them think differently (Bransford & Schwartz, in press).

Recall, for example, that the students primarily generated ideas about the motivational value of projects (see Figure 3). Contrast this with the observations generated by the four experts who comprise the Multiple Perspectives for Challenge 1. One expert points out that he originally thought motivation was the only significant issue, but then as he investigated the issue of learning he found out that the way students are expected to learn in this format often has profound effects on their subsequent abilities to use that information. Another expert notices that the students are all individually seated in the video segment and that there is none of the natural social interaction that often facilitates learning. A third expert points out that it is important to remember that there is a time for lectures and that they can be very effective—the trick is to prepare people to be told. The fourth expert explains that the tests that usually accompany lecture-style instruction often find no parallel in the real world. Consequently students spend an inordinate amount of time learning a skill (e.g., preparing for multiple-choice tests) that becomes obsolete immediately upon leaving school.

After the education students listened to these four perspectives, the class was silent. The instructor parenthetically commented, "It is amazing to find out what you never even thought about." The whole class nodded vigorously in agreement. A useful line of research might formally document whether producing ideas about a topic before hearing different perspectives on that topic increases learners' intellectual engagement with the ideas at hand.

In addition to complementing the Generate Ideas phase, the Multiple Perspectives phase serves a number of purposes. First, the perspectives provide guidance into the topics that the students should explore to learn about the domain. The perspectives do not give away solutions; instead they direct the students to relevant domains of inquiry. In the LBD.Legacy, these domains are cognition, social interaction, and assessment. Second, the Multiple Perspectives feature indicates that a given situation usually has multiple vantage points and that this is acceptable. This is different from much instruction that provides only one model for how to think about the material. Learning multiple entry points into a given topic increases the flexibility of future problem solving (Spiro & Jehng, 1990). Third, there is great added value in having experts comment on the types of demonstration tapes that are currently used in many classrooms. Experts, for example, often notice what is *missing* in the videotape and why that absence is theoretically significant.

One of the exciting potentials of Multiple Perspectives is that it can combine and make available distributed expertise among people who cannot easily be brought together. This has a profound impact on the instructor's ability to adapt and tailor instruction by capitalizing on local resources. And, it serves as a way to create an intellectual community among people who are too busy to meet formally. A good instance of these benefits may be had by jumping ahead for a moment to Challenge 2 of the second inquiry cycle. In Challenge 2 of LBD.Legacy, students are asked to develop a set of design principles for project-based learning and to organize those principles into a helpful visualization.

To help students make headway on this challenge, we recruited local faculty and master teachers for the Multiple Perspectives. Each expert received a video cassette containing a short segment that served as the anchor for Challenge 2. The tape shows a local TV news report in which children launch model rockets as part of a school project. The teachers and faculty were asked to watch the videotape at their leisure. A week or so later, they were videotaped as they gave short commentaries on what they had noticed relevant to design principles for learning. Complementing their brief commentaries, they were asked to suggest a reading that would help students who wanted to learn more. Students also watched the videotape as part of their design challenge, and they generated their ideas in the notebook prior to hearing the experts' perspectives.

Recruiting local experts to make up the Multiple Perspectives on the news broadcast helped to build the local intellectual community. When students saw one professor, for example, they stated, "Hey, we've read stuff by him. So, that's who he is. I've seen him around." Several teams of students took advantage of learning about the scholarly resources in their neighborhood. As we describe later, they decided to interview these faculty as a component of the legacy they left for next year's students. This approach to Multiple Perspectives also helps to build community among the experts themselves. The experts were curious to see what the other experts, their colleagues, had to say. Although they knew one another through college functions, they rarely had a chance to hear one another's expertise. Like the students, after hearing their colleagues' insights, they often commented, "I hadn't even thought of that." One worthwhile question for future research is whether this asynchronous gathering of people has a meaningful impact on the local community. A second question is whether teachers find it sufficiently compelling that they will add their own experts to adapt a Legacy to their local circumstances.

Research & Revise

In Research & Revise, students may take part in many different activities including collaborations, consulting resources, listening to just-in-time lectures, completing skill-building lessons, working with legacies left by students from previous years, and conducting simulations and hands-on experiments. This component of STAR.Legacy is very inclusive and supports most instructional designs. For example, for Challenge 1 of LBD.Legacy, the resources are primarily textual. The students read articles suggested by experts, and they use their textbook as a resource for completing simple tasks that help them understand the potential benefits of project-based learning. For Challenge 2, however, the students analyze video cases, practice instructional techniques with one another, and evaluate Websites that offer project-based lessons. In either case, the key criterion for including a resource is that the instructional materials should help students reach the goals of exploring a challenge and of revising the ideas that they originally generated.

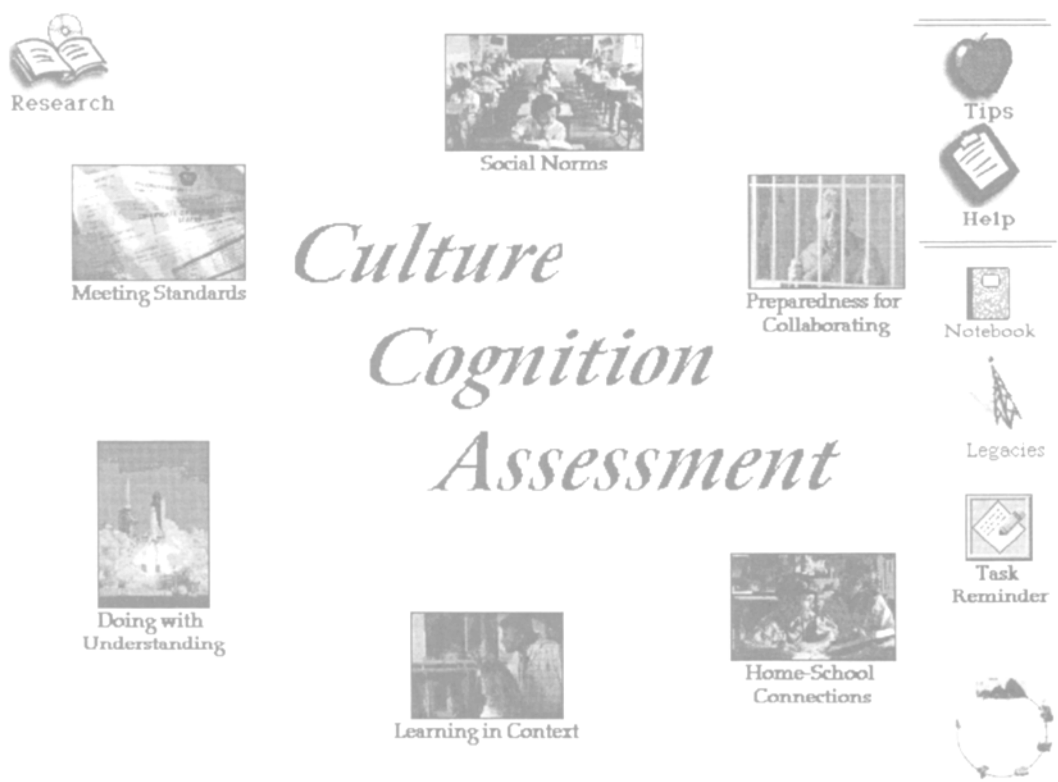
We have found it useful to organize the resources according to the Multiple Perspectives. Figure 4, for example, shows the resource topics available for Challenge 2. Each of the images is keyed to one of the six experts who commented on Challenge 2. By clicking on an image, students move to a page with resources specifically associated with the ideas generated by the relevant expert. This organization helps students and teachers follow those perspectives that seem particularly suited to their needs; we do not assume that students and teachers will necessarily use all the resources available in a STAR.Legacy.

Test Your Mettle

When students think that they have developed their understanding of the original challenge, they are asked to complete Test Your Mettle before they can Go Public with their solution to the challenge. The "test" can take a number of different forms, including multiple-choice tests with feedback, rubrics for evaluating products they plan to make public, and "near transfer" problems. Test Your Mettle is meant as a formative instructional event, not a final exam. It is a chance for students to bump against the world to see if their knowledge is up to the task. If it is not, they should return to Research & Revise to improve their understanding.

For the first cycle of LBD.Legacy, the Test Your Mettle asked the students to evaluate the reasons they had generated for using project-based learning. Each student prepared five reasons. The students met in small groups and selected their best reasons from among their group. They were told that the reasons from each group would be compiled and the class would vote on the top ten reasons. These reasons would then be posted on the World Wide Web through Go Public, and they would be evaluated by students at Stanford University. As the students met in their groups, they began to

Figure 4 ☐ Research & Revise Page for Challenge 2



question what made a good reason, and they wanted examples. Test Your Mettle provided this information. It stated, for example, that a good reason might explain the conditions needed to achieve a benefit from project-based learning. For example, they received a sample frame that stated, "Projects can provide excellent opportunities for assessing student understanding BECAUSE . . . . But, this can only occur IF . . . ." Eventually, the different groups spontaneously began to ask or demand that they get a chance to rewrite their reasons. The students returned to Research & Revise to help them develop an improved set of five reasons.

Test Your Mettle should make thinking sufficiently visible so that a teacher, knowledgeable peer, or even the student, can identify the need for further learning. The preceding example relied on the college students to assess their own work relative to general standards and to one another. This had substantial effects on their evaluations of the quality of their own learning and performance. An important research question is how to support less sophisticated students so they can effectively learn to self-assess (for an approach that uses contrasting cases, see Lin & Bielaczyc, 1998). This is an important skill to develop. Ideally, people should be able to make estimations of their own understanding and make needed course corrections *before* they take a big exam or turn in a big project at the office.

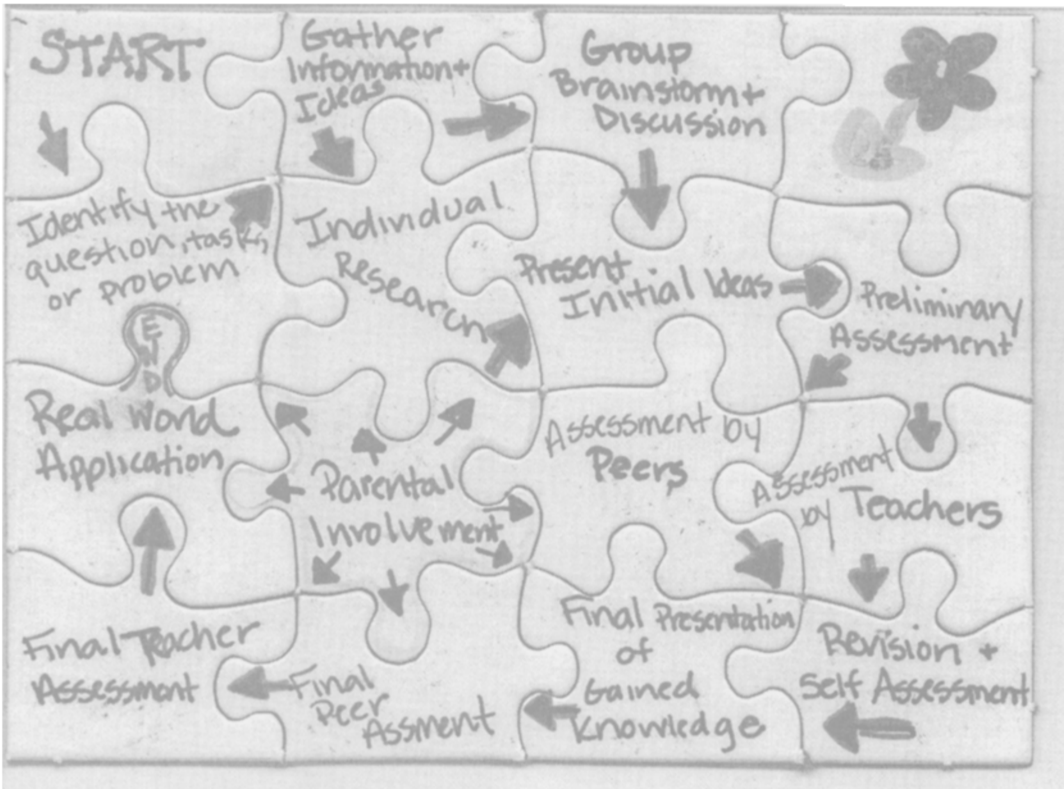
Test Your Mettle should serve as a powerful formative assessment event that guides and motivates students to revise and improve their work. In both math and science, we have found that formative assessment coupled with revision opportunities significantly increases achievement among secondary school students (e.g., Barron et al., 1995; CTGV, 1997; Vye et al., 1998). Although it seems obvious that formative assessment coupled with revision should lead to better performance, it is striking how few classrooms actually encourage formative assessment and revision, especially formative self-assessments undertaken by students. Most classroom science projects, for example, are only evaluated by the teacher at the end (Towler & Broadfoot, 1992). Students never have the chance to "alpha test" and improve their projects (Gardner, 1991).

Go Public

After completing Test Your Mettle, students are prepared to Go Public with their thinking and make available to others their best solutions to the original challenge. Go Public for Challenge 1, for example, required students to post their solutions on the Web for evaluation by an outside audience. There are several reasons that we ask students to Go Public with their knowledge. One is that public presentations of knowledge add a high stakes component that motivates students to do well. For example, we suspect that asking Vanderbilt University students to post their "reasons for project-based learning" on the Web for evaluation by Stanford students had an appreciable effect on their willingness to revise for Challenge 1. Another reason for going public is to make student thinking visible so other students and teachers can appreciate high quality elements of understanding. Consider the case of the design-principle visualizations that students produced for Challenge 2. Many students were annoyed by the unusual nature of the task. Yet, when students publicly presented their solutions in Go Public, the students in the class were uniformly impressed by the creativity and depth revealed in the visualizations—visualizations that ranged from the jigsaw puzzle shown in Figure 5 to a three-dimensional mobile to a Jeopardy™-type game with columns of index cards that had principles on one side and reasons on the other. The opportunity to see each other's ideas is important if for no other reason than that students often do not have a chance to learn or appreciate the more complex ideas of their peers.

There are many different ways that one might encourage students to Go Public. In our work, we have explored asking students to publish to the Internet, to present within their classrooms, to meet with a panel of outside experts, or simply to write in a collective notebook. One approach that we find especially exciting can be done in the context of open-ended challenges where there is little concern about copying of answers. Students publish to the STAR.Legacy itself and help adapt it for future generations. An example of this approach may be found in Challenge 3 of LBD.Legacy. This challenge asks students to write a college-style essay that pres-

Figure 5 ☐ A Design-Principle Visualization Made Public in Response to Challenge 2



ents a good and bad version of a project and uses the class readings to explain the differences. These essays have been added to LBD.Legacy, and therefore have been made public. Students from the class can take home a CD-ROM that includes these essays, and students who take the class in subsequent years will be able to read these legacies to help guide their own work. We say more about leaving legacies below.

MULTIPLE LEARNING CYCLES FOR PROGRESSIVE DEEPENING

As illustrated in Figure 1, STAR.Legacy encourages multiple challenges, represented as increasingly tall mountains. (STAR.Legacy currently supports up to five challenges.) These challenges provide opportunities for students progressively to deepen their knowledge of the topic being explored. The early challenges can prepare students for more ambitious later challenges. Elsewhere, we have found that it is often advisable for students to begin with more circumscribed problems before they take on the complexity and open-endedness of projects (Barron et al., 1998). For example, in one study, 6th-grade students in one of two conditions designed business plans for a booth at their school's fun fair. For this project, students in each condition received the same directive to show how their plans satisfied various financial and logistic constraints. In the Problem-to-Project condition, students first completed a problem-based activity by working on a video-based adventure called "The Big Splash" from the Jasper Adventure series. In the Project-Only condition, students did not complete any preparatory activity prior to designing their fun fair booth. The differences were definitive. Students in the Problem-to-Project condition developed plans that mathematically evaluated the feasibility of different booth plans in terms of cost and likely income. In contrast, students in the Project-Only condition spent most of their time debating the frills that would make the fun booth appealing.

For LBD.Legacy, we used three challenges that were intended to help the students first notice valuable psychological aspects of project-based learning, then consider how to design for those aspects, and finally actually develop lessons according to principles of psychology and instructional design. Challenge 1 asked students to create reasons why project-based learning may be useful. Challenge 2 asked students to create and organize design principles for implementing problem- and project-based curricula. Challenge 3 asked students to design good and bad projects and to explain why they were good and bad in light of their previous readings and activities. For each challenge, the students moved through the usual sequence of generating ideas, hearing different perspectives, consulting resources that included scholarly articles as well as activities, assessing the quality of their work, and then going public.

This may seem like a lot of time to spend on one idea, namely, learning by doing. However, along the way, the students progressively deepened their understanding of important themes in educational psychology. Unlike traditional classes, the themes of cognition, social interaction, and assessment were not taught as self-contained topics, presented in modular chapters. Instead, LBD.Legacy introduced important fields and scholars in the service of helping students understand an important method of instruction.

REFLECTING BACK ON LEARNING AND LEAVING LEGACIES

Reflect Back

We noted earlier that STAR stands for software technology for action and reflection. One way that we encourage reflection comes through the Reflect Back that occurs after completing all the challenges. Students revisit the original Look Ahead activity and compare their new, informed responses to their original work. This gives the students a chance to see how much they have learned and to further extend their knowledge about the domain and their own learning.

To demonstrate that Reflect Back helps students appreciate their own learning, we ran a small experiment with an LBD.Legacy class. Half (11) of the college sophomores in one class were randomly assigned to the experimental, self-comparison condition. At the beginning of instruction with LBD.Legacy, they completed a Look-Ahead that required them to evaluate the compass-building project described earlier. The other half of the students completed a filler activity. Two months later, after completing the three challenges of the LBD.Legacy, all 22 students evaluated the compass-building project as part of Reflect Back. At this time, the self-comparison students were given their original responses. An hour later, masked as part of a different activity, the students were asked to rate how much they felt they had learned in the class on a 7-point scale with 7 being the most. The self-comparison students rated their learning at 5.3 whereas the control students rated their learning at 4.1, a reliable difference; $t(20) = 1.9$, $SE = .63$, $p < .05$, one-tailed. Of course, we cannot prove that the self-assessment students' evaluations were more accurate. Even so, besides the obvious implication for how to increase course ratings, the results indicate that the opportunity to contrast present and past knowledge helps students appreciate how much they have learned.

Students rarely have a chance to appreciate how much they have learned. Even though students usually receive grades, grades are indirect measures of knowledge growth and do not depend on the student's recognizing specific knowledge gains. The lack of opportunities to reflect on knowledge growth may be problematic, especially for lower-achieving students. It is important for students to recognize when they have been successful learners. Reflecting on growth is especially important after learning situations that seemed confusing and perhaps frustrating. We want students to develop a "tolerance for ambiguity" (Kuhn, 1962) and "healthy courage spans" (Wertime, 1979). Seeing their perseverance rewarded with knowledge gains is important to this end (Dweck, 1989). The Reflect Back feature encourages observations about one's learning.

Leaving Legacies

STAR.Legacy capitalizes on technological developments for easily pressing CD-ROMs. Students can receive a CD of a STAR.Legacy after it has been adapted and modified by the teacher and by the class. This CD provides an excellent review of the course content. It can also include the students' solutions to the challenges as well as the legacies they and the teachers have left for the next cohort of students. The students can see that they have created a useful product for others. We believe this can be very motivating for the students as they realize that their insights are valuable.

Not only do the legacies serve the students who create them, they also benefit subsequent students who use the modified Legacy. For example, we are studying the benefits of having middle-school students leave legacies that describe learning stories. The students narrate a personal event or realization that they believe may help the next cohort of students do a good job of learning. We predict that hearing a student from a prior class explain something like, "the challenge was initially frustrating but sticking to it was worth it," will have positive effects.

Another way the legacies can help subsequent students is that they can provide examples of what a good challenge response looks like. For the LBD.Legacy, we have already described how the students left examples of their essays for future generations of users. As another example, we videotaped a few students who described the design-principle visualizations they created for Challenge 2. By including these as legacies, next generation students can get an idea of the creativity that is possible within Challenge 2 (e.g., Figure 5).

Legacies can also add new domain content. This, of course, is part of the idea of flexibly adaptive instructional design—instructional resources can be supplemented with new materials that come from teachers, students, and the local community. The first students who used LBD.Legacy left materials that now constitute important resources. We describe these legacies next because they bear on the question of whether LBD.Legacy can facilitate teachers' abilities to design instruction. In previous years, the instructors of educational psychology had asked students to teach the class for a given topic. The number of "stand-up lectures" was surprising. The students who worked with LBD.Legacy behaved quite differently.

For Challenge 2 of LBD.Legacy, students had to develop a visual representation of design principles. The Multiple Perspectives for this challenge included six experts who each recommended relevant readings. Consequently, Research & Revise included six sets of readings on six topics (see Figure 4). Requiring all the students to read all the articles would have taken too long. Therefore, small groups of students were asked to become experts in a topic. Their task was to develop a firm understanding of their readings and then to create 30 min of instruction that would help the rest of the class learn what they felt were the important points of the material. They were told they could teach any way they wanted, but that their instruction eventually had to be "programmed" into their respective Research & Revise subsection.

Two aspects of the students' work suggest that further development and research on flexibly adaptive instructional design is warranted. The first is the students' capitalization of local resources. The second is their development of instruction that tacitly included important elements of the STAR.Legacy cycle.

Capitalizing on Local Resources

The students took advantage of local resources in two ways. (a) They spontaneously tracked down the local experts shown in the Multiple Perspectives. Some students simply talked to an expert to deepen their own understanding and gather more readings. Other students interviewed and videotaped the experts for inclusion in their instruction. In one case, they even borrowed the raw footage discussed in one of the expert's articles, and used it to create a noticing activity where other students tried to find examples of the theoretical points made in the article. In each of these cases, one can see how the Multiple Perspectives aspect of STAR.Legacy helped to create intellectual community. (b) They found local experts who did not appear in Multiple Perspectives. In one case, for example, the students created a lesson that compared the case-based and clinical methods of legal instruction. To do this, they interviewed law professors and students, as well as lawyers who reflected back on the relationship between their legal education and their practice. In tandem, the two uses of local resources provide a nice example of how STAR.Legacy supports the development of instruction that adapts according to opportunities within the local community.

Incorporating the Inquiry Model

The students' legacies naturally tended to incorporate elements of the learning cycle in flexible ways. Previously, we found that many people who have seen short demonstrations of STAR.Legacy have tended to worry about procedural details. They asked how Test Your Mettle differs from a Challenge, wondered whether students could Generate Ideas in Research & Revise, and questioned whether students could go backwards in the cycle. This worried us because we do not want to imply that learning events can only occur in a given sequence. We want people to think about these important learning events and to use them flexibly in their own instruction. Generating ideas, for example, is fundamental to all learning and it should certainly "be allowed" in Research & Revise. Fortunately, after having seen the students' legacies, we believe that some of people's confusion stems from their short exposure to the STAR.Legacy framework and the novelty of flexibly adaptive instructional design.

The students who used LBD.Legacy adapted its inquiry model for their own legacies. The majority of the students adapted the inquiry model in a similar way. First, they began with a challenge. For example, Figure 6 shows the legacy that one group of students developed to teach about home-school communication. In their legacy, they included four family profiles in written form (one is shown in the figure).

Figure 6 ☐ The Legacy One Group of Students Left as a Resource for Learning About Home-School Connections

They also included four videotaped interviews with teachers. The challenge was to decide which family should go with which teacher and to explain why. A second common component of the students' legacies was the instruction to the class members that they explicitly generate their solutions to the challenge. So, in the case of the family-teacher connection, the class generated its solution to the challenge of matching parents and teachers. Third, the students included the view of an expert or several experts who explained their answers and reasoning. In the family-teacher case, the expert viewpoint was simply a written statement that had been crafted by the students. In the case of a legacy featuring legal education, the students videotaped an expert who wrote an article on legal education. In either case, the students used the experts as a combination of Multiple Perspectives and Research & Revise. This is because the experts pointed out what the students had overlooked, but they also delivered the primary content about what is important to know about the domain. Finally, as the fourth component of their legacies, the students included a Test Your Mettle that allowed the class to extend the knowledge to a new context and to self-assess whether they had learned the intended concepts. For example, one group of students asked the class to apply its knowledge to a previously unseen video of a classroom. The class had to see if it could notice the theoretically important concepts at play in this classroom setting.

All told, the students naturally incorporated the ideas of a challenge, a period of generation, the delivery of expert resources from the community, and the opportunity to test understanding. Some of the students seemed to be aware that they were explicitly adapting the Legacy cycle, whereas others simply thought they had come up with a neat way to teach. In either case, the results are encouraging because they show that the STAR.Legacy framework provided enough of a design theory that the students could create original instruction and could adapt STAR.Legacy to their own instructional goals. A worthwhile line of research, in addition to formalizing the preceding observations, might be to follow teachers into their classrooms to determine whether, when, and how they continue to adapt or create instruction once they leave the luxury of the university setting.

SOFTWARE TOOLS THAT PROMOTE FLEXIBLY ADAPTIVE INSTRUCTIONAL DESIGN

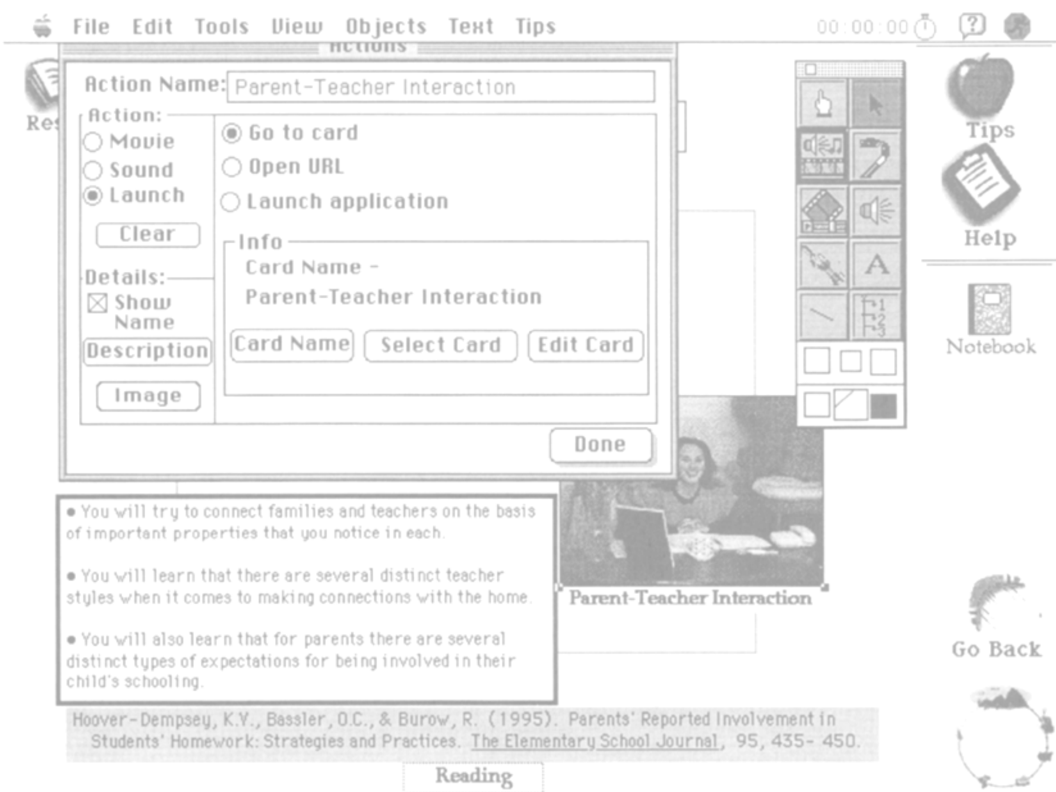
Our surveys of professional designers indicate that a common criterion for a good design model is whether it helps designers make design decisions as efficiently and smoothly as possible. STAR.Legacy, however, requires many instructional decisions that depend on an understanding of learning theory (and on having knowledge of the domain under instruction). We try to scaffold the application of learning theory by including the explicit inquiry cycle and the Tips described earlier. We are also exploring a more inductive scaffold where designers receive a template Legacy that houses several examples of prior designs for each component. The designers can choose one of the examples as a model to guide their design for that component, and they can slowly adapt it by swapping in their own content (Bell, 1998). At this point, however, we are primarily trying to maximize creativity in design rather than prematurely constraining people's designs. Our experiences with the LBD.Legacy suggest that over a more protracted period of time people become comfortable with the STAR.Legacy framework. Additionally, in work with professional instructional designers (Schwartz, Lin, et al., in press), we have noticed how different components, such as Test Your Mettle, increasingly help designers think explicitly about the content they expect students to know. Similarly, we have found that when designers begin to sequence multiple challenges rather than use a single one, they begin to consider what ideas they expect the learners to generalize.

We assume that an understanding of learning goals and events is an excellent way to help designers to adapt to and capitalize on local needs and resources. To this end, we have developed the explicit inquiry cycle. We also assume that the simplicity of authoring in STAR.Legacy encourages flexibility. STAR.Legacy does not include many authoring tools. Those tools that are included are primarily for helping designers access content that is developed and stored outside of the STAR.Legacy shell. For example, LBD.Legacy lists articles that students should consult; it launches video and audio as in the case of Multiple Perspectives; it launches such applications as a Web Browser and a simulation; and it suggests activities that can be completed in the classroom. In this regard, STAR.Legacy is more of an organizational "launch pad" than a place to program large amounts of original content.

Our goal is to provide simple ways for people to author and adapt STAR.Legacy in pedagogically sound fashion. Consequently, we have kept the authoring capabilities quite simple. There is a single tool pallet that people use to include content for any of the components of STAR.Legacy. We have also designed the tools to encourage reflection on learning goals. This is important because we found that when we introduced prototypes of STAR.Legacy, people tended to organize different learning materials according to types of media. For example, in Research & Revise, they organized the learning resources according to useful Internet locations, suggestions for hands-on activities, textual resources, video segments, simulations, and so forth. This is a fine organizational scheme for a merchandise catalog, but ideally, like instructional materials should be organized at the pedagogical level (Murray, 1998) or by the concept they serve, rather than by the media they use. Consequently, we modified the tools to encourage designers to "justify" the learning function for a particular instructional activity. Figure 7 shows an example of the main programming tool that encourages this justification.

Users add a learning event to STAR.Legacy by clicking on a design tool from the pallet shown at the right of Figure 7. The tool opens the dialog box shown at the upper left of the figure. This box asks the designer to define various features of the learning event, including physical appearance, a descriptive account of its learning

Figure 7 ☐ The Programming Tools for Adding a Learning Event to STAR.Legacy



function, and its action. The action defines what type of interactive event occurs when a student or teacher clicks on the interface. These events include playing a movie or sound, opening a browser to a specific location, showing text, simulations, and so forth. In the figure, the selected action opens a new page (shown in Figure 6).

To encourage attention to instructional goals, designers are expected to provide each learning event with a caption and a learning description. The caption is meant to tell students what topic or issue is covered by that particular learning event. During instruction, the description of the learning event appears when the user rolls the mouse over the caption. The description is expected to preview how the activity relates to accomplishing the challenge. This provides the dual functions of encouraging designers to think about meeting instructional goals and helping learners recognize the intent and content of a learning event as it relates to the larger goal of meeting a challenge. The descriptive box at the lower left of Figure 7 begins to meet these goals, although it does not directly map the learning activity back to the challenge of creating design principles for project-based learning.

CONCLUSIONS

Our discussion was founded on a basic assumption: to optimize the effectiveness of an instructional design, it is important to make the design conform to important principles of learning and assessment, and to fit the requirements, skills, and resources of teachers, learners, and their community. We, among others, are working toward a learning theory for instructional design that can help teachers adapt or design instruction for their classrooms. In a course such as educational psychology, the theories of Piaget, Bandura, and Vygotsky provide important psychological insights into learning. However, those theories do not easily translate into instructional practices. We believe a more "user friendly" theory can help people know enough about the process of learning to make sound instructional decisions and adaptations of instructional materials. We also believe that a technological environment that makes it easy to implement this theory is useful in this regard.

To support improved pedagogy as we research learning theory, we have created a multimedia, instructional design environment called STAR.Legacy. STAR.Legacy offers one example of how to organize and facilitate learning in "challenge-based" environments such as case-, problem- and project-based learning. STAR.Legacy supports the design of environments that are simultaneously learner, knowledge, assessment and community centered (elaboration of this point is available in CTGV, in press).

An especially important feature of STAR.Legacy is that it is designed to be flexibly adaptive. Instructional design would be easier if we could assume that we are aiming at a fixed target. Assuming student and classroom homogeneity, however, is analogous to the common assumption that all the people from a particular foreign culture are the same. It is easy, for example, to read about the Japanese educational system and assume that they have only one way of doing things. Anthropologists, however, note that culture does not impose homogeneity; instead, it provides ways for organizing the diversity inherent within its population (Sato & McLaughlin, 1992). Rather than assuming that diversity is the exception, STAR.Legacy is based on the assumption that settings, teachers, and learners have important variability in terms of local practices and standards, learning resources, styles, and prior knowledge. Consequently, we want teachers to be able to adapt instructional materials flexibly to fit their circumstances.

Our discussion of STAR.Legacy focused primarily on our uses of it to improve our practices as college teachers (which often include teaching preservice teachers). The data gathered are informal for the most part, but informative nonetheless. In particular, people have consistently reacted extremely positively to the ability of STAR.Legacy to help them visualize the inquiry process. We also found that students (many of whom were preservice teachers) and designers were able to reflect on learning and to break free from previous ways of doing things.

Our ultimate goal is to use STAR.Legacy as a platform for further research—not so much to study STAR.Legacy but to inquire into general questions relevant to the design of complex instruction. For example, what are the advantages of beginning a unit with a clear overview (including a pretest that helps students visualize the kinds of environments in which they must eventually use their knowledge) versus simply jumping into a challenge? To what extent do opportunities for students to first generate their own ideas help them better appreciate the insights offered by the experts featured in Multiple Perspectives? What is the effect of seeing one's own teacher as a videotaped expert? To what extent might case-, problem-, and project-based lessons benefit from a summarizing lecture designed to help students organize the diverse experiences that were part of their inquiry (see Schwartz & Bransford, 1998)? Our simple study on how to increase students' appreciation of their learning shows how STAR.Legacy readily supports research into these questions and more. Our plan is to continue to collaborate with teachers and designers, and to submit our questions to empirical test. □

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