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ABSTRACT

If learners are to engage in science inquiry, they need significant support, or scaffolding, to help them mindfully do the cognitive science tasks that are just out of their reach. One approach for supporting learners is to design computational tools that incorporate scaffolding features to make new practices accessible and visible so learners can engage in and understand these practices. In order to explore the systematic design and assessment of scaffolding features for software tools, the authors developed "Symphony," a comprehensive scaffolded work environment incorporating process scaffolding features for ninth grade science students performing environmental science investigations. The research questions asked what conceptual process scaffolding strategies would support learners and how can those scaffolding strategies be realized in software. The scaffolding assessment involved three broad steps: identifying specific episodes where students used scaffolds to perform different inquiry activities; assessing how students used different scaffolds in each episode using a new set of assessment criteria; and summarizing the assessment information for each scaffold to describe how students used the different scaffolds over time. By analyzing how learners worked with the Symphony scaffolds, an initial set of design guidelines was distilled for software-based scaffolds. Two example overviews of findings are presented, followed by a description of some scaffolding design guidelines that were distilled from the full set of scaffold overviews. (Contains 33 references.) (AEF)

Scaffolding Design Guidelines for Learner-Centered Software Environments

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Introduction

Many in education view a constructivist "learning by doing" approach as an effective way for novices to develop an understanding of new subjects and practices. This learning perspective is being adopted in many areas, such as science education, where students are encouraged to actively engage in complex science practices. However, science inquiry poses difficulties for novice learners. If learners are to engage in science inquiry, they need significant support, or *scaffolding*, to help them mindfully do the cognitive science tasks that are just out of their reach. One approach for supporting learners is to design computational tools that incorporate scaffolding features to make new practices accessible and visible so learners can engage in and understand these practices. In order to explore the systematic design and assessment of scaffolding features for software tools, we developed Symphony (figure 1), a comprehensive *scaffolded work environment* incorporating *process scaffolding* features for ninth-grade science students performing environmental science investigations (Quintana, 2001; Quintana, Eng, Carra, Wu, & Soloway, 1999). By analyzing how learners *worked with* the Symphony scaffolds, we distilled an initial set of design guidelines for software-based scaffolds.

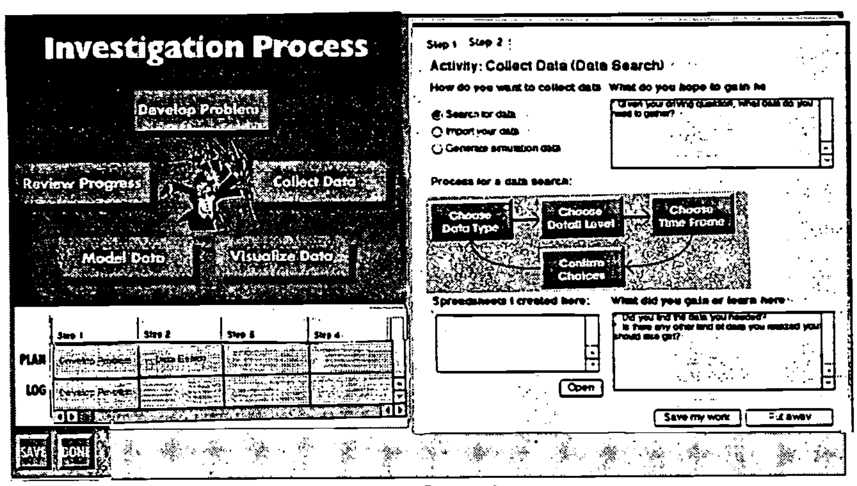

Figure 1: Symphony

Background: Scaffolding for Learners Engaging in Complex Practices

Current science education standards call for students to develop science process and content skills by actively engaging in scientific practices (American Association for the Advancement of Science, 1993; Davis, Hawley, McMullan, & Spilka, 1997; National Research Council, 1996). Such practices involves substantive projects where students make observations; pose questions to study; gather and analyze data; propose explanations; and communicate their results to others. For example, in project-based science (Blumenfeld et al., 1991; Krajcik, Czerniak, & Berger, 1999), students develop science literacy by posing and investigating personally meaningful, open-ended driving questions, usually in pairs or groups, involving a variety of data collection, visualization, modeling, and argumentation activities over an extended time period (e.g., four to ten weeks).

However, while different educational standards bodies state that students should actively perform substantive science investigations, the reality is that learners need significant *support* because of the complexity and open-ended nature of science inquiry (Krajcik et al., 1998). For example, Quintana et al. (1999) note some overall roadblocks for learners who:

- Do not know what activities comprise a science investigation, or what activities to perform at different stages of the investigation.
- Do not know how to do many of the science activities.
- Lack the information that experts use when they investigate problems.

In order to support learners, technology can incorporate *scaffolding* features that make complex practices accessible and mindfully doable by students. A scaffold can be described in the following manner:

- A scaffold helps students do cognitive tasks that are just out of their current developmental and intellectual capability. From an instructional standpoint, scaffolds such as coaching, advising, critiquing, etc., are techniques that teachers use to make complex cognitive tasks accessible for students, (Collins, Brown, & Newman, 1989; Wood, Bruner, & Ross, 1975). From a technological standpoint, software scaffolds, such as templates and prompts for example, can be described as *software features* that help learners perform inaccessible cognitive activities.

- A scaffold supports *mindful work* by learners. In other words, scaffolds should not make new activities too automatic or too easy to complete (Reiser, 2002). Just as good teachers guide students towards solutions without actually giving them the solution, scaffolds should guide and support learners, but in a way that learners still need to think about the work they are doing.

- A scaffold "fades away" (or is removed from the software) when a learner no longer needs the given support (Jackson, Krajcik, & Soloway, 1998). Once learners have internalized the supported task, they no longer need the scaffold, which may now actually interfere with their work.

Research Questions

The Symphony project explored scaffolding issues by focusing on comprehensive process scaffolding in software tools for learners engaging in complex science practices requiring the coordinated use of those tools. For example, scientists use a range of tools to do their different scientific activities: tools for data collection, visualization, planning, modeling, argumentation, etc. We wanted to integrate such a tool set into a single scaffolded work environment for science inquiry. Our research questions concerned the design and assessment of process scaffolds supporting learners doing science inquiry.

Scaffold Design Question

We are interested in having students engage in complex scientific activities, something that is difficult for them to do. Thus we wanted to explore how to design scaffolds that support students in performing science investigations. Our design questions asked what conceptual process scaffolding strategies would support learners and how can we realize those scaffolding strategies in software?

Scaffolding Assessment Question

In terms of scaffolding assessment, we asked: to what extent are process scaffolds successful? How do learners do complex scientific activities with these scaffolds and how does their use of the scaffolds change over time. Scaffolding assessment differs from typical software evaluation, where the main goal is to assess software *usability* (Mayhew, 1999). Scaffolding assessment is primarily concerned with seeing how well scaffolds support learners in doing and learning new practices. In other words, scaffolding assessment needs to consider the "effects with" scaffolding (i.e., how do learners use different scaffolds to perform the task supported by the scaffold?) and "effects of" scaffolding (i.e., what do learners learn about a task after using the software for an extended time period?) (Salomon, Perkins, & Globerson, 1991).

Assessment methods for the "effects of" technology are more straightforward and well-defined: pre- and post-testing, baseline assessments, and transfer task assessment to see what learners know about a work practice before and after using a scaffolded tool. However, there is less work on systematic assessment methods for "effects with" assessment. Thus the Symphony study focused on observing how learners *worked with* the different scaffolds over time to assess how the scaffolds supported learners in their science inquiry.

Related Work

Previous scaffolding research explored how scaffolding techniques used by teachers and mentors could be implemented in software and how scaffolds can fade from software (Guzdial, 1993; Metcalf, 1999). Other researchers are describing and evaluating different kinds of scaffolding strategies (Squires & Preece, 1999). Much scaffolding research revolves around the development of different tools for learners, especially science-oriented software to explore scaffolding in the context of science inquiry. For example, *Model-It* (Jackson et al., 1998; Metcalf, 1999) is a scaffolded tool supporting system dynamics modeling. Model-It not only explored the kinds of scaffolding needed to support system modeling, but also the ways in which the scaffolding can fade. Other scaffolded tools explored supporting the larger science inquiry process. The *Knowledge Integration Environment* (KIE) (Slotta & Linn, 2000) and its successor, the *Web-based Integrated Science Environment* (WISE) helps students integrate evidence to develop and restructure their understanding of complex scientific ideas. The *Biology Guided Inquiry Learning Environment* (BGuILE) (Smith & Reiser, 1998; Tabak et al., 1995) helps students engage in evolutionary biology investigations by *implicitly* incorporating domain-specific strategies and knowledge used by expert biologists. The *Notebook-based Research and Investigative Support System* (NoRIS) (Quintana, Abotel, & Soloway, 1996) was a precursor to Symphony exploring the design of scaffolded software tools for an intermediate to expert-level audience (e.g., undergraduates students to expert scientists) to support them in performing investigations in nuclear engineering.

These tools all explored scaffolding in learner-centered scientific software for supporting different aspects of science inquiry. Our work in the Symphony project focused on comprehensive process scaffolding for the overall science inquiry process, on more systematic scaffolding design and assessment methods, and on articulating some scaffolding "lessons learned" from our observations.

Symphony: Designing and Assessing Process Scaffolds for Environmental Science Investigations

In order to design the necessary scaffolds, we engaged in the learner-centered design (LCD) process we have developed to identify where students need support for their work (Quintana, Krajcik, & Soloway, 2001). Essentially, the LCD process involves:

- *Analyzing* the practice (i.e., science inquiry) to fully identify its important aspects and components.
- *Identifying* areas in the practice where learners may encounter difficulty and need support—we call these areas *learner needs.*
- *Determining* the conceptual scaffolding strategies that address the different learner needs and the specific ways to realize those conceptual strategies in software.

By analyzing scientific practices and our target audience, we saw general areas of complexity for learners and we identified corresponding learner needs to address with scaffolding (table 1) (Quintana et al., 1999):

Table 1: Complexity of Science Inquiry and Corresponding Learner Support Needs

Characteristics of Science Inquiry	Complexity for Learners	Corresponding Learner Needs
Complex	Science inquiry involves completing many activities (e.g., planning, data collection, modeling, etc.), but there are no pre-defined activity sequences for solving a science problem. Different problem solvers perform different activities to investigate the same question.	Learners need to see the range of possible inquiry activities and see how to perform those activities to progress through their work.
Ill-Defined	Science problems are ill-formulated and non-deterministic. Problem solvers explore and iterate through different alternatives in their investigation since there is no set linear path through the space of process activities.	Learners need support to move among the inquiry process activities in a non-sequential, iterative manner.
Opportunistic	There are no explicit stopping rules defining when a science problem is "solved". Accumulated results constantly define the direction of the investigation as problem solvers constantly review their progress and select activities they feel will bring them closer to an adequate answer.	Learners need to understand the rationales for performing certain activities and the kinds of things experts reflect on to assess their results and drive their investigation.

Symphony Process Scaffolds

Unpacking these general learner needs helped us outline more specific learner needs to address with different scaffolding features. For each scaffold, we describe the specific work context for the scaffold, the learner need addressed by the scaffold, the conceptual scaffolding strategy for addressing the learner need, and the specific way we implemented the scaffold in Symphony. Here we present two scaffold examples to ground our discussion. Other Symphony scaffolds are found in Appendix 1.

Example Scaffold 1: Show Activity Options

The "Show Activity Options" scaffold gives learners an overview of the activities that are part of their science inquiry. Table 2 summarizes the scaffold.

Table 2: Summary Description for "Show Activity Options" Scaffold

Context	Learner Need	Scaffolding Strategy
Science inquiry involves a range of different activities, but there are no specific, pre-determined activity sequences to solve a problem. Learners lack an expert's conceptual understanding of science inquiry and thus do not know what activities are involved throughout the inquiry process so they can proceed with their investigations.	Therefore, learners need *activity option information* to see what inquiry activities and metaprocess activities are possible at different points in the investigation.	Process maps provide activity option information with global views of activity spaces. Process maps show the possible work activities with a *conceptual representation* showing the structure and meaning of different activities (Kress & van Leeuwen, 1996). Other researchers say that visual constructs for "visualizing process" can be useful to help learners negotiate and internalize the process (Favorin & Kuutti, 1996; Feurzeig, 1992). Therefore, process maps should describe the space of possible science activities that students can select from to help them proceed with their investigations.

There are two implementations of the "Show Activity Options" scaffold in Symphony. The first is the main planning process map (or *process wheel*) in the planning workspace. The process wheel provides activity-option information describing the space of possible science inquiry activities that students can select from for their investigation plan (figure 2).

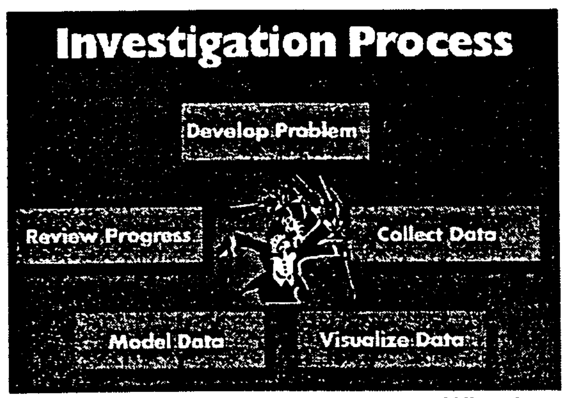

Figure 2: Main Inquiry Process Wheel

The second implementation of the "Show Activity Options" scaffold is the Conductor window (figure 3), which contains a metaprocess map describing the space of possible metaprocess activities to answer the student question "what can I do now?". Where the main process wheel shows the inquiry activities that students can add to their plan, the Conductor window describes higher-level activities that students can perform, such as modifying the plan, performing an activity in the plan, etc.

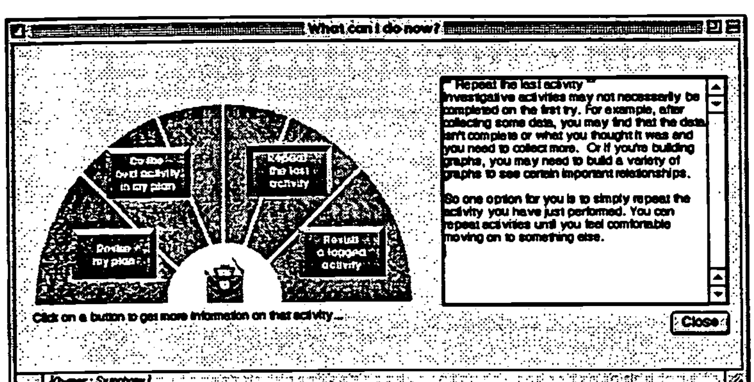

Figure 3: Metaprocess "Conductor" Window

Scaffold Example 2: Show Reflective Information

The "Show Reflective Information" scaffold supports learners with reflection on important parts of their work. Table 3 summarizes the scaffold.

Table 3: Summary Description for "Show Reflective Information" Scaffold

Context	Learner Need	Scaffolding Strategy
Experts need to reflect on various aspects of their investigation. However, reflection is an implicit activity. Learners may not realize the importance of reflection nor understand what they should reflect on as they engage in the science inquiry process.	Therefore, learners need *reflective information* describing the information they should be thinking about when they perform different science inquiry activities.	Explicit reflective information should describe what learners should be thinking about in their investigation and convey the types of information they need to articulate during their investigation.

There are two implementations of the "Show Reflective Information" scaffold in Symphony. First, Symphony includes *prompted activity templates* (figure 4) in two reflective activity workspaces (i.e., a "Develop Problem" workspace and "Review Progress" workspace) as seen in many software tools. Templates provide a notebook service so students can reflect on and articulate the information needed for these activities. Students can record necessary information in the template fields and the "title" above each template field prompts the student about the information they need to think about. For example, the "Develop Problem" workspace has areas for students to reflect on their driving question, hypothesis, problem factors, plans, and notes (figure 4).

The second implementation of the "Show Reflective Information" scaffold includes *prompted activity text fields* (figure 5). Similar to templates, prompted activity text fields are used to record information in different constructive activities (i.e., "Collect Data," "Visualize Data," and "Model Data"). There are two text fields in each constructive activity workspace (e.g., the "Visualize Data" workspace in figure 5). The "plan" text field is for planning the constructive activity (labeled "What do you hope to gain here?") and the "learn" text field is for recording observations or other insights about the activity (labeled "What did you gain or learn here?"). Additionally, *reflective questions* are also found in the "plan" and "learn" text areas to prompt students about other important things to think about in these activities.

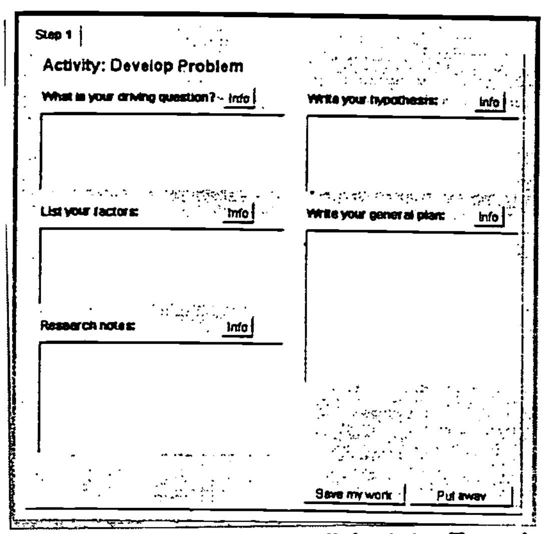

Figure 4: "Develop Problem" Activity Template

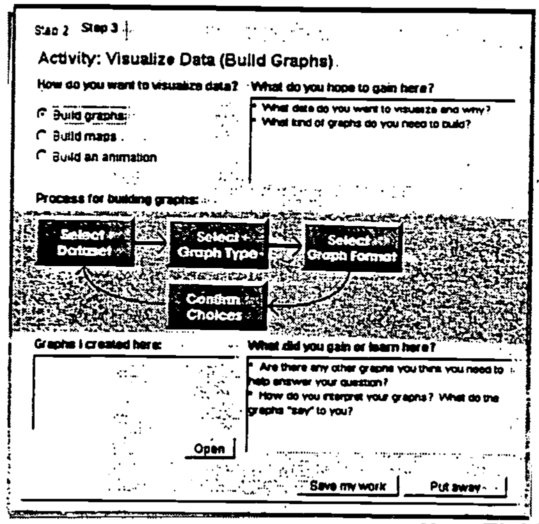

Figure 5: "Visualize Data" Activity Text Fields

Details of the Research Study: Scaffolding Assessment Methods

After designing and implementing the process scaffolds in Symphony, we assessed effectiveness of the scaffolds with a study where ninth-grade students used Symphony to perform air quality investigations. A science teacher in the high school where the study was conducted selected three pairs of students (five boys, one girl) to use Symphony for extended Michigan air quality investigations in a classroom setting. We focused on ninth-grade students because they had less experience in complex scientific investigations, being limited to smaller-scale, "canned" homework questions that involved the linear "scientific method" approach traditionally taught in school. Students engaged in a range of science inquiry activities using Symphony: planning, developing and setting up driving questions; collecting and visualizing data; building and analyzing models; and writing conclusions supported by evidence gathered in the previous activities.

The study took place in an after-school environmental science class where students met for sixty to ninety minutes a day, four days a week. Students received some academic credit for the class and a small stipend. Students worked under the supervision of two people: the author of the study who served as a technical-expert (i.e., the "technical teacher") and a retired scientist who served as a science process and content expert (i.e., the "primary teacher"). Essentially, the teachers adopted a "hands-off" *without the information given* (or *WIG*) approach (Hogan, Nastasi, & Pressley, 2000) where teachers do not "provide direct instruction or other exposure to the conceptual information", instead guiding the students' experience in productive directions without directly giving students the "right" answers. The technical teacher observed the students as they worked, managed the videotaping equipment, provided technical assistance when issues arose with the software, and assisted the primary teacher as needed.

Students investigated driving questions about Michigan air quality organized in three different units. The primary teacher and a high-school science teacher wrote the questions. Additionally, students were able to propose their own questions for investigation. Table 4 summarizes the problem units.

Table 4: Summary of Student Problem Units

Problem Unit	Example Questions	Notes
Unit One Three teacher-written and one student written questions	• Does air quality (as determined by the EPA "dirty half-dozen" pollutants) stay the same or does it vary from day-to-day? • Scenario: You need to shut down air quality monitoring equipment for maintenance. What you recommend as the best time to shut down the equipment? • Is there a regular pattern of change for carbon monoxide? If so, what is it? If not, why is this the case? • Student-written question	These exercises gave students a chance to explore the contents of the EPA pollution data in the database we constructed for their investigations. Students explored data for six pollutants (CO_2, SO_2, NO_2, O_3, PM_{10}, Pb) to see if there were patterns in pollution levels, similar patterns of change for the different pollutants, etc. After they explored the pollution data, students then posed their own question to investigate about pollution levels.
Unit Two One teacher-written question and one student-written question	• Develop a hypothesis about the relationship between nitrogen dioxide pollution and wind. • Student-written question	These exercises gave students a chance to explore the relationships between pollution data and data about other factors that affect air quality, such as weather data. Again, after exploring some possible relationships, students posed their own question to investigate.
Unit Three One teacher-written question leading to independent student investigation	• Given various cities in Michigan, rank the cities in terms in terms of ozone pollution, starting with the city with the worst ozone pollution. • Independent student investigation	Students were given a question with a seemingly obvious conclusion (e.g., Detroit has worse ozone than Manistee National Forest) contradicted by the actual data (e.g., Detroit has less ozone than Manistee). Students had to then conduct investigations using the skills and information gained in the previous units to explain the apparent contradiction.

The units were designed to be open-ended with no single distinct "right" answers and with several investigative paths to pursue. Students had to investigate the questions and write conclusions supported with the work from their investigation. The teachers would review the students' conclusions to see if they were reasonably supported. If their conclusions were weak, the students needed to refine their investigation. When the teachers were satisfied with the conclusions, students could proceed to the next question.

Students worked in pairs on their investigations and were videotaped for the duration of the study. There were three stations in the classroom where students worked—one station per student pair—consisting of computers connected to process video kits that videotaped the computer screen as the students worked, but not the students themselves. The students wore clip-on microphones connected to the process video kits to record their commentary. Thus the primary data for the study was a videotaped record of the students' Symphony work synchronized with their conversations. Students were also interviewed to get their impressions about the various Symphony features.

Assessing the "Effects With" Scaffolding

We observed how the student pairs worked *with* the different scaffolding features in Symphony over an extended time period. The core of the analysis involves a method described by Chi (1997) to iteratively decompose the video data into smaller units of activity that can be interpreted in a more structured manner. Specifically, the scaffolding assessment involved the following broad steps:

- Identifying specific episodes where students used scaffolds to perform different inquiry activities.

- Assessing how students used different scaffolds in each episode using a new set of assessment criteria.

- Summarizing the assessment information for each scaffold to describe how students used the different scaffolds over time.

Assessment Phase One: Coding by Individual Inquiry Activity
We began the assessment by reviewing the student video to identify and code specific episodes corresponding to a major science inquiry activity (table 5). We recorded information about each individual episode into database records describing:

- Researcher observations on the practices students performed in the episode.

- Instances where students needed help with the activities. These observations point out where students need additional or better-designed scaffolds.

Table 5: Episodes for the Symphony Video Analysis

Episodes	Episode Description
Planning	Students determine what activities to select and add to their plan, select activities from their plan to perform, or refine their plan.
Develop Problem	Students work on developing their driving question, hypothesis, factors, specific plan, and research notes.
Data Search	Students collect data needed for their investigation.
Build Graphs	Students build graphs to visualize data they have collected.
Analyze Graphs	Students examine and analyze graphs they have built.
Build Models	Students build system dynamics models to describe the behavior of certain systems.
Analyze Models	Students run and test the system dynamics models that they have built.
Review Progress	Students review the work they have performed, determine if additional work is necessary, and expand on their conclusion.
Incompletion	Students worked on an inquiry activity described above, but did not complete it.
Technical Problem	Students had a technical problem with the software, computer, or computer network.

Assessment Phase Two: Scaffolding Usage Assessment
After identifying *each scaffold* students used in their episodes, we needed to see *how* students used the scaffolds to do the work in each episode. Rather than simply formulating a binary "good" or "bad" rating for each scaffolding feature, we found that we needed to assess the scaffolds along different dimensions to discover finer shades of assessment information from both user-centered tool usability and science inquiry practice perspectives. Therefore we devised a set of criteria to address these considerations (table 6) (Quintana, Fretz, Krajcik, & Soloway, 2000).

Scaffolds are supposed to support the mindful doing of complex tasks, thus the criteria consider how the students did their individual tasks with the support of the given scaffolds. The meaning of the different criteria with respect to a given scaffold must be defined for each scaffold, and in some instances, a criterion may not apply. However, by using a range of evaluation criteria we could get more detailed assessment information to see the trade-offs for each scaffold.

Table 6: Scaffolding Assessment Criteria

Name	Definition
Accessibility	Measures the initial usability of a scaffolding feature to describe whether can access or use the feature. Involves a binary "yes/no" answer: learners can either access the scaffold or they cannot.
Use	Measures whether learners use or ignore a scaffold that is obviously accessible to them. Involves a binary "yes/no" answer: learners either use or do not use an accessible scaffold.
Efficiency	Measures the speed or difficulty of performance when students use scaffolding features to do tasks. This should describe how fast or how easily learners can use a particular scaffolding feature to perform the supported task and how their task performance changes over time.
Accuracy	Measures whether a scaffolding feature supports the correct and appropriate completion of the supported task and how task accuracy improves over time.
Progression	Measures how learners progress through their tasks while using a scaffolding feature: are they working in a linear manner or a nonlinear manner? Learners will initially work in a linear, step-by-step manner. As learners develop expertise in a work task, their work should become more opportunistic, and nonlinear (Schoenfeld, 1987).
Reflectiveness	Measures the amount of task reflection learners engage in when using a scaffold to see how focused they are on their tasks and how their reflection varies over time. This shows whether additional support for "mindful" work is necessary (Salomon et al., 1991).

For each student pair, we reviewed and assessed using the criteria every instance when they used a scaffold. This resulted in three sets of *individual scaffold assessments* per scaffold—one set for each student pair. Next, we summarized every scaffold's individual assessments in each problem unit to create one *scaffold usage summary* (or *SUS*) per scaffold for that problem unit. A scaffold usage summary describes how each student pair used the scaffold over the course of each problem unit. Since students did three problem units, every scaffold had three scaffold usage summaries per student pair.

Assessment Phase Three: Scaffolding Meta-Summarization

Our final assessment phase involved summarizing the scaffold usage summaries from phase two (i.e., creating *metasummaries*) to describe how scaffold usage changed over time and how different student pairs used scaffolds throughout the study. For every scaffold, we created two metasummaries: a *group summary* and a *unit summary*. We created group summaries by consolidating each student pair's scaffold usage summaries for every scaffold. Thus each scaffold had one group summary per student pair describing how the student pair's scaffold use changed over the course of the study. After the group summaries for the three student pairs were complete, we consolidated the group summaries for each scaffold into an *overall group summary* describing how *all* the student pairs used an individual scaffold over time. Thus each scaffold will have one overall group summary.

Similarly, we created unit summaries by consolidating all the student pair's scaffold usage summaries in every problem unit for each scaffold. While group summaries consider how an individual student pair used a scaffold over time, a unit summary describes how *all* the students pairs used a scaffold in a given problem unit. Thus each scaffold will have one unit summary per problem unit. After all the unit summaries for each problem unit were complete, we consolidated the unit summaries into an *overall unit summary* describing how the student pairs used a scaffold over time. Thus each scaffold will have one overall unit summary. Note that a scaffold's overall group and overall unit summaries should closely match to verify each other.

Finally, we reviewed each scaffold's overall group and unit summaries to write a final assessment overview describing the "lessons learned" from the scaffold assessment. The assessment overview should discuss the pros and cons of the scaffold in the given work context and how the scaffold could be redesigned and improved.

Figure 6 describes the scaffold summaries created in this assessment phase. Figure 6 describes the assessment of a general "scaffold x" since we follow this process for every scaffold in the software

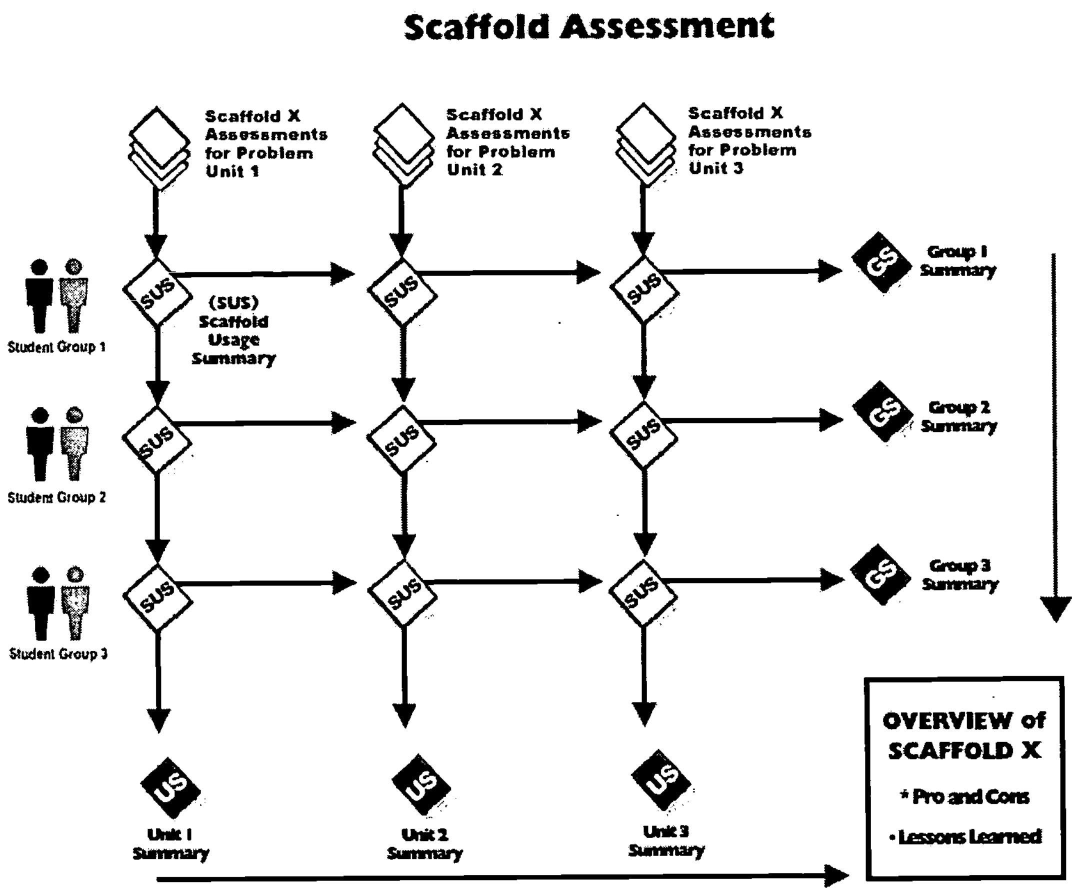

Figure 6: General Overview of Scaffold Usage Summaries

Research Findings from the "Effects With" Scaffolding Assessment

After following the procedure summarized in figure 6, we had an assessment overview for each scaffold in the software. While we cannot fully describe all the assessment information for the entire set of scaffolds (see Quintana (2001) for the full results), below we present two example overviews below. After presenting the example findings, we describe some scaffolding design guidelines that we distilled given the full set of scaffold overviews.

Example Findings: The Process Wheel

The process wheel supported activity selection by visualizing the space of possible inquiry activities students could select for their investigation plan. The process wheel was *accessible* since it is the central interface element on the planning workspace. All the students *used* the process wheel since they could not continue with their investigation until they selected activities for their plan. Students used the process wheel *efficiently*, selecting activities for their plan without difficulty. So from a user-centered standpoint, the process wheel was usable for the students.

In terms of the more learner-centered criteria, we saw that *accuracy* and *progression* were connected because linear *progression* (i.e., occasions when learners selected activities in the clockwise "wheel order" implied by the wheel) led to lower *accuracy*. Most students initially selected all the process wheel activities in the implied clockwise "wheel order" without considering whether they actually needed those activities in their plan. As a result, the students selected extraneous activities (e.g., adding modeling to the plan even though modeling was not needed in a problem), thus lowering their *accuracy* rating. Over time, *accuracy* increased and *progression* became more nonlinear. At that point, students selected appropriate activities as needed without strictly following the wheel order, thus adding fewer extraneous activities to their plan.

Reflection was more visible in earlier problem units, when there was more discussion between students about the activities to select. As students proceeded through the different problem units, there was less discussion, but since students quickly selected accurate activities with nonlinear progression, implying that they better understood the purpose of the different inquiry activities.

The assessment results suggest some design implications for process maps. A visual representation like the process wheel can help steer students into thinking about what activities to perform before they rush to perform them, something that students are prone to do (Collins, 1996). Of course, the risk of a visual representation like the process wheel is that students will simply follow the order implied in the wheel. In that case, the wheel becomes less of a support and more of a crutch, where some students are simply following the wheel order rather than making mindful selections.

Designers certainly need methods to visualize activity spaces for learners facing a new work practice. But an effective visualization should force learners to be mindful about their activity selection. Designers must be wary of the implications that a visual representation brings (e.g., the implied clockwise order in a wheel). Certainly, complex work practices like science inquiry can be partially ordered (e.g., one cannot graph data before collecting data) and this partial order could be visually represented to help learners see "appropriate" selections. However, designers should be cautious in the choice of representation so learners will not blindly follow any implied order in the representation, resulting in less-mindful and inappropriate activity selection.

Example Findings: Activity Templates and Text Fields

The activity templates and text fields supported learner reflection and information recording throughout an investigation. Students *used* the activity templates fairly well. The templates were *efficient* to use and *accessible* since the reflective activity workspaces consist solely of the templates.

Reflectiveness ratings for both activity templates were good as we saw many instances when students discussed the information they had to record. In those instances when students had to work alone, they still showed explicit signs of reflection: making audible comments about their work (e.g., commenting that their hypothesis is wrong or commenting about new tasks to perform), discussing their work with teachers, or reviewing prior work as they recorded information in the template.

Accuracy ratings were mixed because while students wrote mostly appropriate information when they used fields in the template, they used different template fields to varying degrees. We also saw instances when students would verbalize important information (raising the *reflectiveness* rating) without recording the information in the template (lowering the *accuracy* rating because recording information was part of the task). For example, students would comment on new activities to perform, but they would not modify their plan to record those changes. It was important that the students were thinking about their science activities. But the fact that students would verbalize information without recording implies that more support is needed in the template so students can keep an explicit work record.

One drawback of a template is that it is simply a collection of text fields and learners might see the fields as being optional, especially if they are not clear about the information they should be recording. One approach for addressing this might be to use a "forcing" mechanism in the template so that learners cannot continue with other work until they have entered appropriate information in all the template fields. Another design consideration would be to allow other media types and other modes of information entry, such as voice entry. Since students did discuss important observations without recording them in the template, perhaps a mechanism allowing learners to talk to the system and leave quick "voice notes" would allow them to quickly leave an explicit record of their actions.

Unlike the full activity templates, we found that students rarely used the "plan" and "learn" activity text fields in the constructive workspaces. One reason could revolve around the perceived student focus of the activity workspaces. The reflective activity workspaces (i.e., "Develop Problem," "Review Progress") consist *solely* of the template, so the activity's focus is on reflection and recording information. However, the constructive activity workspaces contain a variety of elements (see "Visualize Data" workspace in figure 5): the activity text fields, a process map to help construct the relevant artifact for the activity (e.g., a graph), and artifact lists. So students saw artifact construction as the primary focus of the workspace and instead felt that recording plans and observations were more ancillary activities.

The activity text fields are straightforward to use, but they need to be made more explicit in the activity workspaces. One approach to emphasizing the importance of reflecting on plans and observations would be to have the system force the students to write planning information before artifact construction. For example, students could not build graphs until they recorded some plans for their graphing activity. Furthermore, after building some graphs, students would not be able to proceed with another inquiry activity until they recorded some observations so that they would be forced to slow down and think about the artifacts they are building. However, it may be difficult to implement a system that effectively determines when the learner has written "appropriate" information.

Another approach might be to allow learners to connect information to the different work activities they are performing. For example, if students entered a specific plan earlier in the work process, they might simply stop and connect that portion of their plan to the current activity. If students later record observations about some artifact like a graph, they should be able to connect their observations back to the artifact itself. Some argumentation tools, such as Belvedere (Suthers, Weiner, Connelly, & Paolucci, 1995) attempt to support students in building an argument by visually connecting hypotheses with evidence. A similar approach can be used so learners can create and connect plans, artifacts, and conclusions to see the importance of reflecting on artifact construction plans and artifact analysis.

Interpretation: Scaffolding Design Guidelines

After completing the scaffold overviews, we reviewed and synthesized the assessment information to determine some initial scaffolding design guidelines explaining why students used the different scaffolds in the manner that they did. We distilled these guidelines by isolating different scaffolding characteristics to see if there were similar scaffold use patterns correlated with the scaffolding characteristics. We looked at the following scaffold characteristics:

- *Visibility* of the scaffold in its workspace
- *Essentialness* of a scaffold's use in terms of doing the target work
- *Coupling* of a scaffold with other scaffolds in a workspace
- *Usability* of a scaffold
- *Representation* of a scaffold in terms of its graphical or textual nature

The following sections describe each of these scaffold characteristics and the associated scaffold design guidelines describing how that characteristic may have impacted scaffold use by learners. (A summary table of the Symphony scaffolds and their associated characteristics is found at the end of appendix 1.)

Scaffold Visibility

Visibility describes how visible a scaffold is in the workspace where it is located. Table 7 shows the two descriptions of scaffold visibility.

Table 7: Definition of Scaffold Visibility

Scaffold Visibility	Description
Visible	The scaffold is always visible in the workspace where it is located.
Triggered	The scaffold must be triggered by some control in the workspace or triggered by the system.

Visibility is important because our findings showed that visible scaffolds were used more than triggered scaffolds. Most of the triggered scaffolds conveyed explanatory information (e.g., information that explained some science inquiry concept). However, even though students showed the need for such information (e.g., students had questions about factors or hypotheses), they asked teachers or other students for this information instead of triggering the scaffolds. Thus the first design guideline suggested by these findings is:

Guideline 1: Scaffold Visibility. Scaffolds and scaffold content should be made as visible as possible because learners may not scaffolds. Rather than having learners trigger a scaffold, scaffolds should be initially visible and learners can remove them when no longer needed.

This guideline suggests that designers should not assume that learners would trigger scaffolds. Triggered scaffolds can be problematic because some learners may not want to admit that they need help and will not trigger the scaffold. Even scaffolds triggered by the system tend to be ignored. For example, Model-It triggers messages to students when they have not performed important parts of the system modeling task. However, students tended to ignore these supportive scaffolds (Metcalf, 1999).

Avoiding triggered scaffolds in favor of visible scaffolds runs counter to the traditional user interface approach for designing help features. Typically in user interface design, users trigger online help features when they need help. However, the Symphony findings suggest that the approach for LCD scaffolds should be reversed. Rather than turning scaffolds on when they need help, scaffolds should be initially visible when a given workspace opens. Learners can then turn the scaffolds off when the help is no longer needed.

Scaffold Essentialness

Essentialness describes how essential it is for learners to use a scaffold to proceed with their work tasks. Table 8 shows the three descriptions of essentialness.

Table 8: Definition of Scaffold Essentialness

Scaffold Essentialness	Description
Essential	Use of a scaffold is mandatory for learners to perform a work task so they can proceed with their work.
Semi-Essential	Learners can use a scaffold to do a given work task so they can proceed with their work, but there are other scaffolds that can be used to perform the same task.
Optional	Learners can choose to use a scaffold to perform a given work task, but performance of the task is not mandatory (although it would probably be helpful).

The Symphony findings showed that learners tended to bypass the optional scaffolds and use the essential and semi-essential scaffolds. This is obvious for the essential scaffolds, since learners need to use those scaffolds to proceed with their work. But all the optional scaffolds were bypassed except for the prompted activity templates. Thus the second design guideline suggested by these findings is:

Guideline 2: Scaffold Essentialness. Scaffolds should be designed to have an essential character. There should be few optional scaffolds because learners may bypass them and miss the support needed to perform certain work tasks.

Note that the lack of scaffold essentialness on its own does not necessarily mean scaffolds will be ignored. For example, the prompted activity templates were optional, but still used well. However, the findings suggest that if scaffolds are optional, there needs to be a way of focusing the learner's attention on the scaffold to emphasize the scaffold's importance. For example, optional scaffolds could either have enticing triggers to draw the learner's attention or be essential so learners will have to use the scaffold to proceed with their work.

Having more essential scaffolds can force learners to engage in important parts of the work process. The trade-off for designers involves incorporating essential scaffolds that do not result in frustrating software. If the collection of essential scaffolds requires learners to work in a strictly regimented manner, learners may become frustrated and lose interest in the work. One approach could be to use essential scaffolds for learners who are starting out with the software. These learners would ostensibly be new to the work, so forcing scaffold use would be advantageous to expose them to the different work tasks. When learners develop a better internal work model and become more opportunistic in their work style, the essential scaffolds may begin to interfere with their work. At that point, learners could fade scaffolds by "reducing" their essentialness (i.e., making the scaffolds optional). Thus, scaffold essentialness seems closely tied to the fading issues studied by Metcalf (1999).

Scaffold Coupling

Coupling describes how a scaffold is connected or related to other scaffolds in the workspace where they appear. Table 9 shows the three descriptions of coupling.

Table 9: Definition of Scaffold Coupling

Scaffold Coupling	Descriptions
Tightly Coupled	The scaffold is connected to other scaffolds on a workplace such that the scaffolds work in concert or an action a scaffold visibly affects the connected scaffolds.
Loosely Coupled	The scaffold appears with other scaffolds on a given workspace, but the scaffolds are not connected in any manner.
No Coupling	The scaffold appears alone on a given workspace.

Coupling effects were seen in the Symphony constructive workspaces (e.g., figure 5), which consist of the loosely coupled prompted activity text fields (for reflection) and process maps (for constructing data sets). None of these scaffolds are directly dependent on the others, nor do the actions on one scaffold affect the others. The findings showed that learners used the process maps but bypassed the activity text fields. This is not surprising, especially when looking at the essentialness measure: the process maps were essential for building a graph but the activity text fields were optional. Since students can proceed with their constructive activities without taking notes, students instead focused on the more essential scaffolds, bypassing the text fields. So the third design guideline suggested by these findings is:

> **Guideline 3: Scaffold Coupling.** Scaffolds that appear together in a workspace should be as tightly coupled as possible so that learners will focus their attention on all the scaffolds. Loosely coupled scaffolds risk being bypassed by learners if their focus is only directed to some subset of scaffolds on the workspace.

Coupling is important because it is one way of directing the learner's focus on the scaffolds so they will perform the various work tasks. Scaffolds that appear alone will certainly get the learner's focus. For example, the prompted activity templates, which were not coupled since they appeared alone on a workspace, were used well despite being optional. If there are multiple scaffolds on a workspace, tightly coupling them will help direct the learner's focus. Since scaffolds must be used together, or since action on one scaffold results in a visible effect on another scaffold, the learner is implicitly drawn to all the scaffolds. If a workspace does contain multiple, loosely coupled scaffolds, then those scaffolds might be made essential so that learners will not bypass them.

Scaffold Usability

Usability simply describes whether there were any usability problems with the scaffolds. Table 10 shows the three descriptions of usability.

Table 10: Definition of Scaffold Usability

Scaffold Usability	Description
Detrimental	There were enough usability problems to interfere with appropriate use of the scaffold so that the learner could not or did not do the underlying task.
Problematic	There were usability problems with the scaffold, but the learner was still able to perform some or most of the underlying work task.
None	There were no major usability problems with the scaffold.

Usability can definitely affect how learners use scaffolds. In the Symphony study, there were three major categories of scaffold usability problems:

- Problems with scaffold "triggers." There were some examples of this problem, such as scaffold buttons that did not appear to be a clickable control to some students, or scaffold buttons with generic labels that did not specifically convey the information provided in the scaffold.

- Problems with non-obvious scaffold functionality. One scaffold was functionally overloaded so that some functionality was obvious, but other functionality was not.

- Problems with confusing scaffold functionality. One scaffold had a similar graphical layout to another, but different behavior.

Thus usability issues did affect the use of the scaffolds. So the fourth design guideline suggested by these findings is:

> **Guideline 4: Scaffold Usability.** Scaffolds need to be usable or learners will not be able to mindfully perform the supported tasks. However, scaffolds should not be designed to make new tasks too automatic to complete.

Usability problems can be frustrating and can cause learners to bypass scaffolds, thus missing important work activity. So user-centered design principles need to be considered for scaffold design to ensure that usability issues do not interfere with scaffold use. However, there is a trade-off between "just enough" and "too much" usability. Since ease-of-use is not the primary concern for learner-centered design, some user-centered design principles may need to be disregarded in scaffold design to avoid making work tasks too easy, thus discouraging the "mindful work" goal for LCD. This trade-off between user-centered goals (i.e., tool efficiency) and learner-centered goals (i.e., mindful work) is an ongoing research topic (e.g., Rappin, Guzdial, Realff, & Ludovice (1997); Sedighian, Klawe, & Westrom (2001)).

Scaffold Representation
Representation simply describes the visual nature of the scaffold. Table 11 shows two descriptions of representation.

Table 11: Definition of Scaffold Representation

Scaffold Representation	Description
Graphical	The scaffold is primarily graphical in nature.
Textual	The scaffold is primarily textual in nature.

Our findings showed no direct correlation between the scaffold's visual representation and how the scaffold was used. So the fifth design guideline suggested by these findings is:

> **Guideline 5: Scaffold Representation.** Neither textual or graphical scaffold representations are inherently better or worse than the other. Textual scaffolds can be simple, but useful for learners. Graphical scaffolds can be powerful and motivating, but misleading to learners.

Intuitively, it would seem that graphical scaffolds would be more motivating and effective for learners than textual scaffolds. However, there was no evidence that graphical scaffolds were inherently more effective than textual scaffolds. Some textual scaffolds were used well (e.g., prompted activity templates), while some were not (e.g., prompted activity text fields). So scaffolds were not used or bypassed simply because of their textual nature.

Conversely, graphical scaffolds can be effective, but they must be designed with caution so that they are not misleading to learners. Designers need to be wary of information that learners might interpret from a visual representation. For example, the Symphony process wheel is useful for conveying the space of inquiry activities in the science inquiry process. However, the design of the process wheel was somewhat misleading because the wheel representation conveyed an unintended activity selection order during planning.

Concluding Remarks and Future Directions

In classroom trials, students effectively used Symphony to engage in extended air quality investigations. By looking at how students used the individual Symphony scaffolds during their investigations, we gained information describing the strengths and weaknesses of different process scaffolds and how different features of scaffolds affected the learners' scaffold use. The scaffolding assessment information led to a set of initial scaffolding design guidelines for designers implementing scaffolding features to support novice learners in doing complex cognitive tasks. The scaffolding design guidelines give some insight into different properties of software features and how those features should be defined to support learners. However, it is still incumbent on designers to consider the information in the full guideline set to understand the interplay between the different scaffold characteristics and the inevitable design trade-offs that are found in any design activity. Our future work involves using our LCD methods to continue designing scaffolds for new complex tasks and assessing the scaffolds with a range of learners (e.g., K-12 students) on a range of devices (e.g., desktop to handheld computers) to test, refine, and expand our initial set of scaffolding design guidelines to provide design guidance for designers of learner-centered scaffolded tools.

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Appendix 1

The following describes some of the other Symphony scaffolds in the classroom study.

Scaffold Name: Show Activity Procedures

Table 12: Summary Description for "Show Activity Procedures" Scaffold

Context	Learner Need	Scaffolding Strategy
Many of the activities in the science inquiry process, especially constructive activities, are complex and require procedures that learners do not know how to perform.	Therefore, learners need *procedural information* to see how to perform the constructive activities, such as data collection, data visualization, and modeling.	Just as process maps visualize activity spaces, process maps can similarly incorporate process visualization techniques to convey the procedures needed to complete certain inquiry activities.

Symphony implements the "Show Activity Procedure" scaffold by using *flow diagrams.* A flow diagram is a task-oriented directed map displaying the procedure for constructing different artifacts, such as a graph (figure 7). Similar flow diagrams are used to help students build data sets and models. A flow diagram is a *classificational diagram*, which describes an active process and shows the interconnections between the parts of the process (Kress & van Leeuwen, 1996). Pressing a button in the flow diagram triggers the appropriate portion of the tool used to complete the selected part of the artifact construction task.

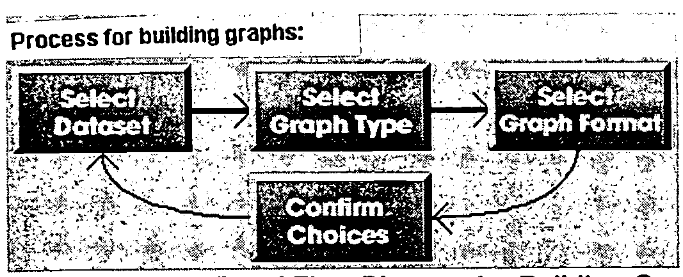

Figure 7: "Visualize Data" Flow Diagram for Building Graphs

Scaffold Name: Show Explanatory Information

Table 13: Summary Description for "Show Explanatory Information" Scaffold

Context	Learner Need	Scaffolding Strategy
Experts use different kinds concepts, rationales, and terminology about a variety of work aspects to perform different activities. However, learners lack or have incomplete knowledge of these work concepts and activities.	Therefore learners need *explanatory information* that describes different concepts and terms from the work practice (e.g., What is a "hypothesis"?) along with the purposes of the different inquiry activities so they can proceed with their work.	Different guides can explain important concepts learners need to complete their tasks within the appropriate activity workspaces. The guides are a form of *work-oriented help* that support learners with some aspect of the underlying work practice rather than helping with tool operation (the traditional help provided in software).

Symphony implements the "Show Explanation Information" scaffold in two ways. First, Symphony implements rollover activity rationale guides (figure 8). Process wheel activities and flow map tasks have a connected activity rationale guide describing the given task or activity. These guides appear when the mouse pointer is positioned over the activity or task buttons.

Second, Symphony implements "Info" guides to explain concepts (e.g., driving question, hypothesis, factors, general plan, research notes) in the "Develop Problem" workspace (figure 9). A guide for a particular concept is triggered from an "Info" button next to each template field.

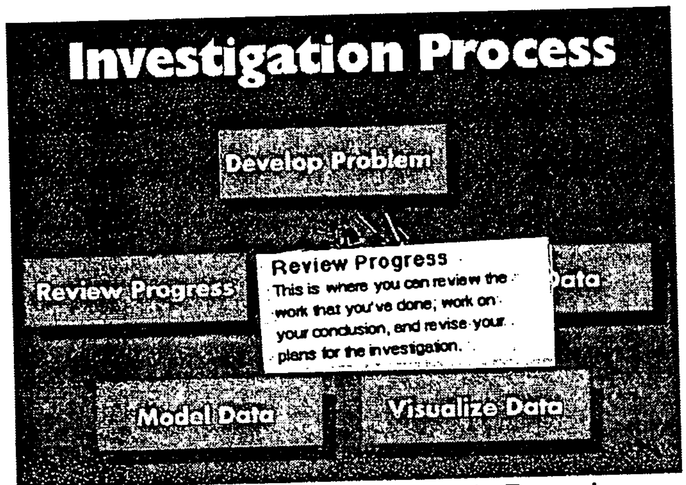

Figure 8: Rollover Activity Guide Example

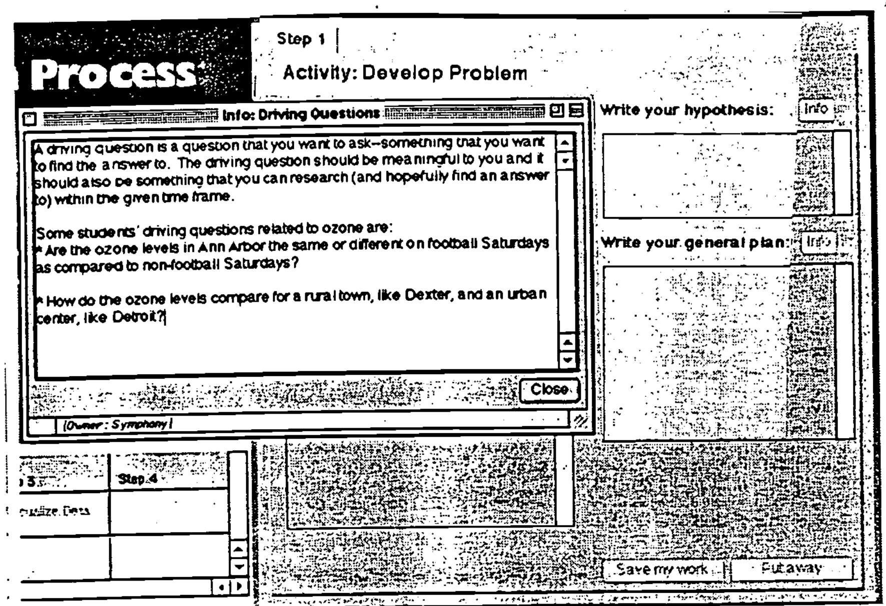

Figure 9: "Info" Guide Example

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Scaffold Name: Allow Flexible Planning

Table 14: Summary Description for "Allow Flexible Planning" Scaffold

Context	Learner Need	Scaffolding Strategy
Because of the chaotic, iterative nature of the science inquiry process, flexible planning is important to refine the direction of the investigation as new results warrant. Scientists constantly modify their existing plans by rearranging activity order, deleting activities, or adding new activities. But learners may not be fully aware of the implicit planning task and thus lack experience in planning and managing the complex set of activities needed to engage in the work.	Therefore learners need explicit support for the implicit planning activity that experts perform to refine and maintain a record of the investigation.	Explicit flexible planning services are needed to give learners a mechanism for incrementally planning their investigation. Explicit planning services for learners can help them see the importance of constant planning in an iterative, chaotic work practice.

Symphony implements the "Allow Flexible Planning" scaffold with a *plan/log grid* (figure 10) for plan setup and modification. Students set up plans by taking activities from the process wheel and adding them to the plan row of the grid. Students modify their plans by moving activities to different locations in the grid or by removing activities from the grid. By serving as a flexible time line, the plan grid provides a *temporal analytical diagram* (Kress & van Leeuwen, 1996) that relates a part-whole structure (i.e., the overall plan) as successive stages (i.e., the steps in the plan) to support flexible planning and re-planning.

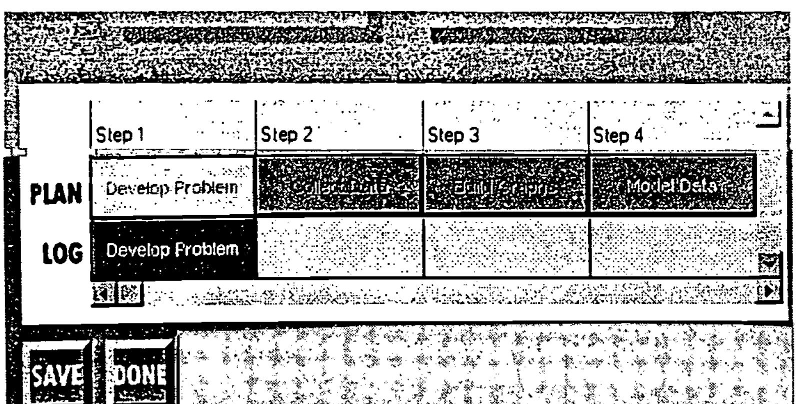

Figure 10: Planning in the Plan Row of the Plan/Log Grid

Scaffold Name: Support Non-Sequential Activity Traversal

Table 15: Summary Description for "Support Non-Sequential Activity Traversal" Scaffold

Context	Learner Need	Scaffolding Strategy
Since science inquiry is opportunistic and chaotic, the work involves moving between the different process activities (e.g., moving from planning to data collection to visualization to planning, etc.) in a non-sequential manner. Experts can work in a chaotic manner unlike learners who are more familiar with linear work.	Therefore learners need support to facilitate non-sequential movement between the different activities in the science inquiry process so that they can work in an opportunistic manner.	A SWEet should *allow flexible activity traversal* with mechanisms that help learners quickly traverse the different activity work spaces as needed throughout the investigation rather than forcing a linear activity sequence.

Symphony implements the "Support Non-Sequential Activity Traversal" scaffold in two ways. First, Symphony uses *tabbed activity workspaces* (figure 8) to facilitate rapid movement between activities. Symphony allows students to open several activity workspaces simultaneously and move quickly through them (via tabbing) in the iterative, non-linear manner indicative of realistic science work. Second, Symphony uses the *log row* buttons in the Plan/Log grid (figure 6) to display activities that learners have already worked on. Learners can open previous activity workspaces by pressing the log row button corresponding to the activity.

Table 16 summarizes the different Symphony scaffold characteristics and general findings.

Table 16: Scaffold Characteristics and General Findings

Scaffold	Visibility	Essentialness	Coupling	Usability	Representation	General Findings
Process wheel	Visible	Essential	Tightly coupled with the plan/log grid	None	Graphical (Map)	Useful, albeit somewhat misleading for activity selection.
Plan/log grid	Visible	Essential	Tightly coupled with the process wheel	Problematic: Overloaded functionality results in non-obvious plan "modify" functionality	Graphical (Grid)	Used to set up plans, but not to modify plans.
Prompted activity templates	Visible	Optional	None	None	Textual	Used well to record information for reflective activities.
Flow maps	Visible	Essential	Loosely coupled with activity text fields and artifact lists	None	Graphical (Map)	Used to access artifact construction services.
Tabbed activity workspaces	Visible	Semi-essential	Tightly coupled to activity workspaces	Sparse labels could be confusing	Graphical (Tabs)	Used with increasing frequency.
Log row buttons	Visible	Semi-essential	Tightly coupled to plan/log grid	None	Graphical (Push buttons)	Used with decreasing frequency.
Workspace artifact lists	Visible	Semi-essential	Loosely coupled with activity text fields and flow maps	None	Textual	Used well to access artifacts.
Prompted activity text fields	Visible	Optional	Loosely coupled with flow maps and artifact lists	None	Textual	Used the "learn" fields sparingly. Did not use the "plan" fields.
Artifact table-of-contents	Triggered	Semi-essential	None	Problematic: Trigger button could be more visible	Textual (Uses buttons, but typical textual list)	Used, but less than artifact lists.
Rollover activity rationale guides	Triggered	Optional	None	None	Textual	No indications that they were used.
Problem development "Info" guides	Triggered	Optional	None	Problematic: Non-descriptive labels on trigger buttons	Textual	No indications that they were used.
"Conductor" metaprocess map	Triggered	Optional	None	Problematic: • Confusing trigger button • Confusing layout	• Graphical (Map) • Textual	Not used very often.

References

American Association for the Advancement of Science. (1993). *Benchmarks for Science Literacy*: Oxford University Press.

Blumenfeld, P. C., Soloway, E., Marx, R., Krajcik, J. S., Guzdial, M., & Palincsar, A. (1991). Motivating Project-Based Learning. *Educational Psychologist, 26*(3 & 4), 369-398.

Chi, M. (1997). Quantifying Qualitative Analyses of Verbal Data: A Practical Guide. *Journal of the Learning Sciences, 6*(3), 271-315.

Collins, A. (1996). Design Issues for Learning Environments. In S. Vosniadou & E. De Corte & R. Glaser & H. Mandl (Eds.), *International Perspectives on the Design of Technology-Supported Learning Environments*: Lawrenece Erlbaum Associates.

Collins, A., Brown, J. S., & Newman, S. E. (1989). Cognitive Apprenticeship: Teaching the Crafts of Reading, Writing, and Mathematics. In L. B. Resnick (Ed.), *Knowing, Learning, and Instruction: Essays in Honor of Robert Glaser*: Lawrence Erlbaum Associates.

Davis, M., Hawley, P., McMullan, B., & Spilka, G. (1997). *Design as a Catalyst for Learning*: Association for Supervision and Curriculum Development.

Favorin, M., & Kuutti, K. (1996). Supporting Learning at Work by Making Work Activities Visible Through Information Technology. *Machine-Mediated Learning, 5*(2), 109-118.

Feurzeig, W. (1992). *Visualization Tools for Model-Based Inquiry*. Paper presented at the Conference for Technology Assessment, Los Angeles.

Guzdial, M. (1993). *Emile: Software-realized Scaffolding for Science Learners Programming in Mixed Media*. Unpublished Ph.D. Disseration, University of Michigan.

Hogan, K., Nastasi, B. K., & Pressley, M. (2000). Discourse Patterns and Collaborative Scientific Reasoning in Peer and Teacher-Guided Disscussions. *Cognition and Instruction, 17*(4), 379-432.

Jackson, S. L., Krajcik, J., & Soloway, E. (1998). *The Design of Guided Learning-Adaptable Scaffolding in Interactive Learning Environments*. Paper presented at the Human Factors in Computing Systems: CHI '98 Conference Proceedings, Los Angeles.

Krajcik, J., Blumenfeld, P., Marx, R., Bass, K. M., Fredericks, J., & Soloway, E. (1998). Middle School Students' Initial Attempts at Inquiry in Project-Based Science Classrooms. *Journal of the Learning Sciences, 7*(3 & 4), 313-350.

Krajcik, J. S., Czerniak, C., & Berger, C. (1999). *Teaching Children Science: A Project-Based Approach*: McGraw-HIll.

Kress, G., & van Leeuwen, T. (1996). *Reading Images: The Grammar of Visual Design*: Routlege.

Mayhew, D. J. (1999). *The Usability Engineering Lifecycle*: Morgan Kaufmann Publishers.

Metcalf, S. J. (1999). *The Design of Guided Learner-Adaptable Scaffolding*. Unpublished Ph.D. Dissertation, University of Michigan.

National Research Council. (1996). *National Science Education Standards*: National Academy Press.

Quintana, C. (2001). *Symphony: A Case Study for Exploring and Describing Design Methods and Guidelines for Learner-Centered Design*. Unpublished Ph.D. Dissertation, University of Michigan.

Quintana, C., Abotel, K., & Soloway, E. (1996). *NoRIS: Supporting Computational Science Activities Through Learner-Centered Design*. Paper presented at the Proceedings of ICLS '96: Second International Conference on the Learning Sciences, Evanston, IL.

Quintana, C., Eng, J., Carra, A., Wu, H., & Soloway, E. (1999). *Symphony: A Case Study in Extending Learner-Centered Design Through Process-Space Analysis.* Paper presented at the Human Factors in Computing Systems: CHI '99 Conference Proceedings, Pittsburgh.

Quintana, C., Fretz, E., Krajcik, J., & Soloway, E. (2000). *Evaluation Criteria for Scaffolding in Learner-Centered Tools.* Paper presented at the Human Factors in Computing Systems: CHI 2000 Extended Abstracts, The Hague, The Netherlands.

Quintana, C., Krajcik, J., & Soloway, E. (2001). Exploring a Description and Methodology for Learner-Centered Design. In W. Heineke & L. Blasi (Eds.), *Methods of Evaluating Educational Technology* (Vol. 1). Greenwich, CT: Information Age Publishing.

Rappin, N., Guzdial, M., Realff, M., & Ludovice, P. (1997). *Balancing Usability and Learning in an Interface.* Paper presented at the Human Factors in Computing Systems: CHI '97 Proceedings, Los Angeles.

Reiser, B. J. (2002, January 7-11, 2002). *Why Scaffolding Should Sometimes Make Tasks More Difficult for Learners.* Paper presented at the Proceedings of CSCL 2002, Boulder, CO.

Salomon, G., Perkins, D. N., & Globerson, T. (1991). Partners in Cognition: Extending Human Intelligence with Intelligent Technologies. *Educational Researcher*(April).

Schoenfeld, A. H. (1987). What's All The Fuss About Metacognition? In A. H. Schoenfeld (Ed.), *Cognitive Science and Mathematics Education*: Lawrence Erlbaum Associates.

Sedighian, K., Klawe, M., & Westrom, M. (2001). Role of Interface Manipulation Style and Scaffolding in Cognition and Concept Learning in Learnware. *ACM Transactions in Computer-Human Interaction, 8*(1), 34-59.

Slotta, J. D., & Linn, M. C. (2000). The Knowledge Integration Environment: Helping Students Use the Internet Effectively. In M. J. Jacobson & R. B. Kozma (Eds.), *Innovations in Science and Mathematics Education: Advanced Designs for Technologies of Learning* (pp. 193-226). Mahwah, New Jersey: Lawrence Erlbaum Associates.

Smith, B. K., & Reiser, B. J. (1998). *National Geographic Unplugged: Classroom-Centered Design of Interactive Nature Films.* Paper presented at the Human Factors in Computing Systems: CHI '98 Conference Proceedings, Los Angeles.

Squires, D., & Preece, J. (1999). Predicting Quality in Educational Software: Evaluating for Learning, Usability, and the Synergy Between Them. *Interacting with Computers, 11*, 467-483.

Suthers, D., Weiner, A., Connelly, J., & Paolucci, M. (1995). *Belvedere: Engaging Students in Critical Discussion of Science and Public Policy.* Paper presented at the AI-Ed 95: The 7th World Conference on Artificial Intelligence in Education, Washington D.C.

Tabak, I., Sandoval, W. A., Smith, B. K., Agganis, A., Baumgartner, E., & Reiser, B. J. (1995). *Supporting Collaborative Guided Inquiry in a Learning Environment for Biology.* Paper presented at the CSCL '95 Proceedings.

Wood, D., Bruner, J. S., & Ross, G. (1975). The Role of Tutoring in Problem-Solving. *Journal of Child Psychology and Psychiatry, 17*, 89-100.

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