

Scaffolding Analysis: Extending the Scaffolding Metaphor to Learning Artifacts

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The scaffolding metaphor was originally developed to describe the support given by a more expert individual in a one-on-one interaction. Since then, the notion of scaffolding has been applied more broadly, and it has been transformed and generalized. Most recently, it has been used by researchers in the learning sciences to describe features and functions of technological artifacts, especially those of educational software. In this article, we present an analytic framework that we believe can guide and systematize these new uses of the scaffolding metaphor. In this new framework, “scaffolds” are not features of artifacts or situations, nor is “scaffolding” something that may be occurring (or not) in a given situation that we observe. Rather, a *scaffolding analysis* is a kind of comparative analysis that we perform on learning interactions. Because this analysis is comparative, it always produces results that are relative to specific choices that we make in framing the comparative analysis. In this article, we present a theoretical argument for our proposed framework and illustrate the definition by applying it to two software environments.

Just over a quarter century ago, the term *scaffolding* was introduced to psychology by Wood, Bruner, and Ross (1976). In that first incarnation, scaffolding was used to describe the support given by a more expert individual in one-on-one tutorial interactions. Since then, this term has been adopted by researchers that study learning and human interaction from diverse perspectives, and it has been transformed and generalized. Most recently, it has been used by researchers in the learning sciences when discussing features and functions of learning artifacts, especially those

of educational software (e.g., Brush & Saye, 2001; Davis & Linn, 2000; Guzdial, 1994, 1998; Jackson, Krajcik, & Soloway, 1998; Kolodner, Crismond, Gray, Holbrook, & Puntambekar, 1998; Krajcik, Soloway, & Blumenfeld, 1998; Linn, 2000; Williams, Burgess, & Bray, 1998).

More specifically, when we speak of *learning artifacts*, we have in mind physical objects that are designed by some individuals to support the learning of other individuals. Our primary focus in this article is on *technological artifacts* such as calculators and computer software. However, our discussion has relevance for attempts to extend the scaffolding metaphor to other external artifacts such as graphs and written text. Furthermore, some of our arguments may help clarify the notion of scaffolding even when it is applied to situations, such as one-on-one tutoring, that have been its traditional focus.

It is our belief that the recent adaptations of the notion of scaffolding have spawned a productive line of research and have had beneficial effects on curriculum and technology design. However, as we attempt to make clear, these new uses of the scaffolding metaphor fall outside the original intent of Wood et al. (1976) as well as the intent of psychologists and educators who closely followed Wood et al. For this reason, we believe that it is worthwhile for researchers in the learning sciences to reflect on how exactly the notion of scaffolding should be applied to the new situations that are our concern. That is the purpose of this article. We present a primarily theoretical analysis of what scaffolding has meant in the past. Then, based on that analysis, we propose a framework that we believe can provide some guidance for learning scientists in applying the scaffolding notion to situations in which technological artifacts figure prominently.

Our stance is that there is no single right answer to what the word scaffolding means or to how the notion of scaffolding should be interpreted when applied to the analysis of artifacts. Rather, we believe that the most productive approach is to set out to design an analytic framework that is useful for our purposes.

In some respects, the analytic framework we propose might be seen to depart from previous attempts to apply the notion of scaffolding to technological artifacts. In our framework, “scaffolds” are not features of artifacts or situations nor is scaffolding something that may be occurring (or not) in a given situation that we observe. Rather, a *scaffolding analysis* is a kind of comparative analysis that we perform on learning interactions. In the version of scaffolding analysis that we argue for, one explicitly specifies two situations to compare, a *scaffolded* situation and a *base* situation. Then one looks to see how the additional features of the scaffolded situation lead to changes in performance along a particular dimension, which must also be specified. Because this analysis is comparative, it always produces results that depend on the specific choices that we make in framing the comparative analysis.

In the next section, we work toward unpacking how scaffolding has thus far been treated in the education and psychology literature. We are particularly concerned with describing how this notion has been transformed in more recent learn-

ing sciences research concerning educational technology. Next, we propose our analytic framework and describe some prototypical applications of the framework. We then apply our framework to discuss design features of two software environments. Next, we briefly discuss how our framework might be extended to address issues of learning and fading. Finally, we conclude the article.

UNPACKING PRIOR TREATMENTS OF SCAFFOLDING

Some First Examples

In the original article by Wood et al. (1976), the authors described a laboratory situation in which individual 3-, 4-, and 5-year-olds worked on a task with an adult tutor. The task involved building a pyramid out of 21 specially designed blocks, each of which had pegs, holes, and depressions that constrained their assembly. The children readily engaged in playing with the blocks, but they found the task difficult and required significant assistance from the tutor. After leaving 5 min for free play, the tutor would begin by showing the child how pairs of pieces could be put together and by drawing the child's attention to some important features of the blocks. Then, once the child got going, the tutor would try to assist as little as possible, only intervening when the child got into difficulty or stopped working on the task.

This is a paradigmatic example of the type of situations that have figured in discussions of scaffolding. A child works on a task with help from an adult that would otherwise be beyond the child's capabilities. For the most part, the activity is not structured as a lesson in which the adult teaches one new thing, then another, then another. Rather, the child works on a given task, and the adult intervenes only when the child needs assistance. We believe that most readers would feel that it is straightforward to apply the notion of scaffolding to this situation. Statements such as "the tutor is scaffolding the child" appear unproblematic.

Now we consider an example that involves an individual working with external artifacts and no immediate interpersonal interaction. Imagine an episode in which a student is working alone to solve the mathematics word problem shown in Figure 1.¹ In this problem, two trains start at a single location and move in opposite directions. The student is given the speed of each train and asked to find how far apart the trains are after 3 hr. In addition to the statement of the question, the student is given the diagram shown in Figure 1 as well as paper and pencil and a calculator to use in performing calculations. Can the notion of scaffolding be productively applied to understand this situation? If so, how can it be applied?

One approach that we could imagine adopting (but which we ultimately reject) is to identify specific features of this situation and call those features scaffolds. For

¹This problem is adapted from an article by Hall, Kibler, Wenger, and Truxaw (1989).

Two trains leave a station at the same time. They travel in opposite directions. One train travels at 55 mph. The other train travels at 30 mph. How far apart are the trains after 3 hours?

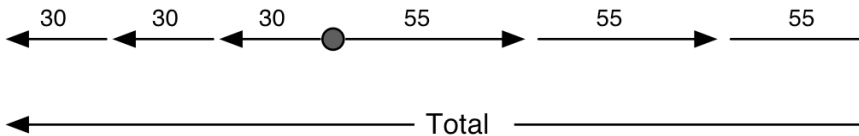


FIGURE 1 The train problem.

example, we can imagine saying that the calculator is acting as a scaffold. It reduces the work that the student must do, allowing her or him to focus on other aspects of the problem perhaps in a manner that is more productive for some learning objectives.

The statement “the calculator is a scaffold” has some straightforward appeal, but it raises some questions. If we start picking out tools and calling them scaffolds, which of the available tools should be included? Should every tool that allows people to be more successful be called a scaffold? For example, if a calculator is a scaffold, then it seems possible that we can call the paper and pencil a scaffold. This is clearly problematic, however. If our notion of scaffolding becomes overly inclusive, then it may cease to be useful.

Furthermore, it is not even clear that it makes intuitive sense to call the calculator a scaffold. The use of calculators has become extremely common, so common that today’s students might have them available routinely throughout their lives. If a calculator is a fixed component of mathematics problem-solving activity, can it still be called a scaffold?

Similarly, the diagram in Figure 1 might be taken to be a scaffold that is provided to the student. The diagram is not strictly necessary to the statement of the problem and its presence might be very helpful for a student. However, as with the calculator, there is a slippery slope here. Should every piece of information in the question that is not strictly required be considered a scaffold?

Finally, note that even if we decided to include all tools in a list of scaffolds, it would be hard to know how to look at a situation and recognize all of the tools involved. For example, does a table surface count as a tool? Do learned procedures count?

How Scaffolding Has Been Defined: The Precise Language

As a first step toward answering the questions posed in the preceding section, we begin by looking at the precise language that is used by some authors to define

scaffolding. In the article by Wood et al. (1976), the first mention of scaffolding appears when they stated that the interaction between a tutor and another individual generally involves a “‘scaffolding’ process that enables a child or novice to solve a problem, carry out a task or achieve a goal which would be beyond his unassisted efforts” (p. 90).

In some of the articles that followed Wood et al.’s (1976) original work, this passage was cited explicitly and used, word for word, as a definition of scaffolding (e.g., Palincsar, 1986; Stone, 1998b). Other articles, including some with an emphasis on educational technology, employed very close paraphrases of Wood et al.’s original definition. Some examples are the following:

Scaffolding refers to support provided so that the learner can engage in activities that would otherwise be beyond their abilities. (Jackson et al., 1998, p. 187)

Scaffolds are tools, strategies, and guides which support students in attaining a higher level of understanding; one which would be impossible if students worked on their own. (Brush & Saye, 2001, p. 334)

Scaffolding enables the learner to achieve goals or accomplish processes normally out of reach. (Krajcik et al., 1998, p. 39)

Scaffolding is:

- Support which enables a student to achieve a goal or action that would not be possible without that support.
- Support which facilitates the student learning to achieve the goal or action without the support in the future. (Guzdial, 1994, p. 3)

In still other cases, authors have used language that is not quite a paraphrase of Wood et al. (1976) but nonetheless has very similar content. The following are some passages from an often-cited work by Collins, Brown, and Newman (1989) that uses the notion of scaffolding as part of a characterization of *cognitive apprenticeship*:

A key aspect of coaching is the provision of scaffolding, which is the support, in the form of reminders and help, that the apprentice requires to approximate the execution of the entire composite of skills. (p. 456)

Scaffolding refers to the supports the teacher provides to help the student carry out the task. ... When scaffolding is provided by a teacher, it requires the teacher to carry out parts of the overall task that the student cannot yet manage. (Collins et al., 1989, p. 482)

One other feature of the language used by some authors deserves reporting here. Some authors make a particular point of emphasizing that the learner will gradually be able to achieve the goal or action with less and less support, a process that is typically called *fading*. For example, Guzdial (1994) elaborated on his previous definition by saying that

A critical component of scaffolding is fading. If the scaffolding is successful, students will learn to achieve the action or goal without scaffolding. For students to practice the action or goal without the scaffolding, the scaffolding must fade. However, scaffolding should not be all-or-nothing. Instead, scaffolding should be adapted to individual student needs, typically through gradual reductions in scaffolding. (p. 4)

Similarly, Stone (1998a) stated that in earlier literature on scaffolding

The support the adult provided was assumed to be temporary and was gradually withdrawn, in order to foster a transfer of responsibility from the adult to the child. (p. 349)

Finally, Collins et al. (1989) also included fading as a key feature:

Once the learner has a grasp of the target skill, the master reduces (or fades) his participation, providing only limited hints, refinements, and feedback to the learner, who practices successively approximating smooth execution of the whole skill. (p. 456)

Observations Concerning These Definitions

Now that we have related the definitions of some authors in their own words, we need to look closely at the content of these definitions. In doing so, our purpose is to draw out implicit assumptions that are shared by these various definitions as well as across the broader literature on scaffolding. Our description of these implicit assumptions takes the form of four observations. The first three observations are relatively distinct. The fourth observation synthesizes Observations 1 through 3, but restates them from a new perspective.

Observation 1: There is an implicit comparison. Our first observation is that there is an implicit comparison at the heart of all of the definitions given previously and that exists throughout the gamut of uses of the notion of scaffolding. For example, Wood et al.'s (1976) original definition involves a comparison of what an individual can achieve when there is a "scaffolding process," with what is possible in "unassisted efforts." In Wood et al.'s laboratory experiment, the unassisted case was simply the one in which the child builds the pyramid alone without help from an adult.

For most of the literature that closely followed Wood et al. (1976), this is precisely how the unassisted case was understood. Across this early literature, the researchers have tended to look at tutorial interactions. For example, Greenfield (1984) described how girls learn to weave in Chiapas, Mexico. According to Greenfield's account, the girls learn by engaging in weaving tasks in the presence of expert weavers, who assist them when needed. Similarly, Rogoff and Gardner

(1984) described a laboratory study in which adults help children learn to put groceries away in a mock kitchen. In these examples, the unassisted case was at least implicitly the situation in which the expert or adult was not present.

From the point of view of theory construction, introducing a comparison of this sort is sensible and powerful. Basing our analysis around a comparison means that we are freed from having to understand all features of the learning interaction. Instead, we can focus only on the things that differ between the two situations being compared.

However, the introduction of a comparison imposes an additional requirement on any careful analysis of scaffolding in a particular situation. If we wish to accept some version of Wood et al.'s (1976) definition, then it is essential that we are able to state what the unassisted case is to which we are comparing. For the case of the tutorial interactions considered by Wood et al. and the authors that followed, this does not seem to be too big a difficulty. There is an implicit—but clear—choice for the unassisted situation.

However, if we attempt to extend the notion of scaffolding beyond tutorial interactions, then it may be less clear what the unassisted case should be. This can be illustrated with our hypothetical example previously in which a student solves the train problem. We might choose, as the unassisted case, the situation in which the student does not have a calculator. However, this choice is not absolutely necessary. As we suggested before, it is also sensible to think of the calculator as a fixed feature of the task of solving mathematics problems. So, we might instead choose as the unassisted case the situation in which the student is not given a diagram.

The problem is that any of these choices are sensible, and they lead to very different conclusions about the nature of the scaffolding that is occurring. If one wishes to extend the range of application of the scaffolding notion, then one must develop a way to deal with this problem.

Observation 2: Something is held constant. In Observation 1, we commented that definitions of scaffolding seem to imply a comparison of the situation of interest with an unassisted situation. In describing one of the situations as scaffolded and the other as unassisted, we are emphasizing that the two situations differ from each other. However, for the comparison to make sense, there must also be something that is invariant; there must be some sense in which the individual is at least trying to “do the same thing” across the two situations.

The assumption of this invariance can be seen as following very directly from a broader change in theoretical orientation in which early discussions of scaffolding were embedded. Namely, there was increased interest in the work of the Soviet psychologists, especially Vygotsky (1962, 1978), and there was increasing disenchantment among some researchers with both Piagetian and behaviorist perspec-

tives.² Greenfield (1984), for example, contrasted scaffolding with Skinner's notion of "shaping":

Shaping involves a series of successive approximations to the ultimate task goal. ... Scaffolding, in contrast, does not involve simplifying the task during the period of learning. Instead, it holds the task constant, while simplifying the learner's role through the graduated intervention of the teacher. (p. 119)

In shaping, the task is seen as gradually changing as the learner's abilities change. In contrast, for researchers such as Greenfield (1984), it was a critical feature of scaffolding situations that the task is seen as remaining constant.

The notion that individuals can be trying to do the same thing across two situations makes sense, at least intuitively. However, in practice, there can be quite a bit of subtlety about what this actually means. In its purest form, the early literature has made some very strong assumptions in this regard. It is assumed that the task can be broken down into discrete components. In the unassisted situation, the novice has responsibility for all of these components. In the scaffolded situation, the expert does some of the components, and the novice does others. If the interactions continue, then gradually the novice takes back more and more of the components until the novice is able to accomplish the entire task on his or her own. Throughout all of this, the nature and sequence of the individual components is considered to be fixed; all that is different is who—the expert or the novice—has responsibility for the various components. Thus, in this earliest and purest version of the scaffolding literature, there has been a very strong sense in which one is trying to achieve a performance that remains the same across the two situations being compared.

However, as the historical context has shifted and the motivations for invoking the scaffolding metaphor have changed, this strong condition has been gradually relaxed. Note, first, that the pure versions of task invariance include an assumption that the task is decomposable. Wood et al. (1976) were explicit in stating their belief in this decomposability:

The acquisition of skill in the human child can be fruitfully conceived of as a hierarchical program in which component skills are combined into "higher skills" by appropriate orchestration to meet new, more complex task requirements. (p. 89)

More recent literature has reacted against this assumption of decomposability. For example, Stone (1993) argued that the expert should not be seen as simply leading the novice through a predetermined sequence of steps. Instead, the expert and novice jointly construct a means of understanding and negotiating the situation.

²See Stone (1998a) for a historical overview of the evolution of the scaffolding metaphor and a discussion of how this evolution was driven by broader theoretical movements.

As soon as we relax the assumption of decomposability—and we relax the assumption that there is no fixed sequence of steps—then it becomes less clear what it can mean that there is something that is held constant. Indeed, in some more recent literature that has discussed scaffolding, authors have explicitly stated that they no longer assume that there is a task that is held constant. For example, Jackson et al. (1998) divided software scaffolds into three types: “supportive,” “reflective,” and “intrinsic.” The last of these types, intrinsic scaffolds, “change the task itself.”

The more that our learning artifacts transform the task, the harder it will be to understand how the learner might be doing the same thing when they make use of these artifacts. We return to this issue in later sections.

Observation 3: The task is an expert task, and the support will ultimately be faded. In the preceding section, we observed that early accounts of scaffolding implicitly assume that there is a task that is held constant across the situations that are being compared. Our third observation is that at least in the earliest discussions of scaffolding, this constant task was assumed to have some specific characteristics: It was assumed that the task is one that is characteristic of expert activity and that the novice will ultimately perform the task without assistance. For example, the basket weavers discussed by Greenfield (1984) learned to weave baskets by doing just that—weaving baskets, and it is assumed that gradually the expert’s assistance will be faded until the novice can perform this task alone.

These assumptions seem to be in line with our paradigmatic notions of scaffolding. However, we should be aware that if we are strict in applying these assumptions, then we rule out the possibility of applying the scaffolding metaphor to a wide range of situations. Suppose, for example, that we assume that a student who is solving the train problem will always have a calculator. If this is the case, then the second assumption says that we must not think of the calculator as performing a scaffolding function because the support is not intended to be faded.

More profoundly, if strictly adopted, these assumptions seem to rule out the case in which the tasks students perform in school are not the same tasks for which they are being prepared. For example, in science classes, students often engage in conducting laboratory experiments, and they receive a variety of kinds of help from teachers and artifacts. However, in many cases, the goal of having students conduct these experiments is not to have them become scientists themselves and be able to conduct experiments without help. Instead, students may engage in classroom science experiments so that they will ultimately be able to function as scientifically literate citizens.

Observation 4: There is an analysis of function. Our last observation cuts across the first three, giving a wider frame for discussion. The assertion we support here is that when we talk about learning situations in terms of scaffolding, we are inherently performing analyses that have to do with the function of ele-

ments of the situation. Once this assertion is in place, some work of philosophers on the notion of function can be seen as relevant. The observation we borrow from philosophers is that to make statements about function, we must explicitly specify an analytic framework. The ideas presented here follow a number of chapters in an edited book by Buller (1999) that is primarily concerned with the notion of function as it appears in biology.

We begin by returning once again to the original article by Wood et al. (1976). Wood et al.'s article includes a list of scaffolding functions that we have reproduced in Table 1. This list is introduced by the following passage:

Several functions of tutoring—"scaffolding functions"—were hinted at in the introduction. We can now elaborate more generally upon their relation to a theory of instruction. What can be said about the function of the tutor as observed in this study? (Wood et al., 1976, p. 98)

The same list given by Wood et al. appears in Stone (1993). Greenfield (1984) presented a similar list of five functions, which we have also reproduced Table 1.³

The lists of functions in Table 1 are not just afterthoughts; they are central to discussions of scaffolding. As we argue throughout the remainder of this article, analyses of scaffolding involve making claims regarding how certain elements or actions in a learning interaction function to enhance the performance of an individual. Stone (1998a), in his summary of the history of the scaffolding metaphor, seemed to agree that analyses of function are central:

The first extended treatment of the metaphor seems to be in an article by Wood, Bruner, and Ross (1976). Those authors used the metaphor as an analytic device to aid in understanding the functional role of the support provided to young children by their parents during joint problem solving activities. (p. 345)

However, there are some difficulties associated with any analysis of functions. One way to see the difficulty is to notice that it is hard to know what to include when listing functions. For example, Wright (1973) asked by what criteria we would decide that the function of the heart is only to pump blood and not also to make heart-pumping sounds. It seems, intuitively speaking, that one would like to be able to state that the function of the heart is only to pump blood. Yet how can one rule out other possible functions such as the making of sounds?

As theorists, there are a number of approaches we can take to remedy this problem. One approach is to try to tune our definition of function so that it rules out

³Greenfield (1984) introduced her list when talking about the physical scaffolds employed by construction workers. However, Greenfield went on to say that the same list is relevant to the metaphorical scaffolding that occurs in learning interactions.

TABLE 1
Lists of Functions of Scaffolding From Various Authors

<i>Wood, Bruner, & Ross (1976); Stone (1993)</i>	<i>Greenfield (1984)</i>
1. Recruitment of interest in and adherence to the task	1. Provides a support
2. Reduction in degrees of freedom	2. It functions as a tool
3. Direction maintenance	3. It extends the range of the workers
4. Marking critical features	4. It allows the worker to accomplish a task not otherwise possible
5. Frustration control	5. It is used selectively to aid the worker when needed
6. Demonstration	

some candidate functions and keeps only the ones we think we should keep. This is the approach taken by Wright (1973) in his seminal article on functions. Wright tried to draw a line, for example, between “true” and “accidental” functions. (In the case of the heart, pumping blood is the true function, and the making of sounds is an accidental function.)

Cummins (1999) provided us with an alternative to the approach taken by Wright (1973). Cummins advocated a stance in which claims about function are always relative to a framework that is imposed by the analyst. In Cummins’ definition, any statement about the function of an element, x , is relative to two choices: (a) a choice of a larger system, s , in which x is embedded, and (b) a choice of a *capacity* of s that we wish to explain such as the capacity of the heart to move blood. In this approach, the meaning of the term *function* is not constructed so that any particular object, such as the heart, only has certain specific functions. Rather, we simply accept that any statements about function are relative to a particularly explanatory framework that is invoked by the analyst. Depending on the framework that is invoked, we might reasonably decide that the function of the heart is to pump blood or to make heart-pumping sounds.

We believe that because we are interested in the design of learning artifacts, we are best served by adopting a more open approach in line with the approach advocated by Cummins (1999). When researchers design artifacts, they should be prepared to consider the functions of the artifacts as viewed from multiple perspectives, and with multiple aims in mind. To narrow the definition to a single function would simply, we believe, cut off potentially useful avenues of analysis.

Statements about function lie at the very center of discussions of scaffolding, and we do not mean to suggest that talk of function should be eliminated or even made less central. Rather, the primary implication of this discussion is to argue that to use the notion of function productively, we must explicitly identify an explanatory framework. Really, this is a more general way of stating the implications of Observations 1 and 2. What we concluded in those earlier observations was that

analyses of scaffolding depend on the choice of an unassisted task and an invariant. This dependence on explanatory framework is a central theme when we present our own analytic framework in the next section.

APPLYING THE SCAFFOLDING METAPHOR TO LEARNING ARTIFACTS

We are now ready to present our analytic framework for applying the notion of scaffolding to learning artifacts. In some respects, the framework we present should not be a surprise to readers given the preceding discussion. For the most part, all that we do is take the parts of the definition that have been implicit in the work of preceding researchers and either make them explicit in our framework or explicitly exclude them.

When making decisions about what to embrace and what to reject in our framework, we were guided by a specification of what we wanted this framework to do. In particular, we intended to produce a framework that is useful for three types of analysis.

1. Design rationale: We wanted an analytic framework that is useful for capturing the rationale behind the design of an instructional innovation, particularly educational technology. In this case, the analysis we envision would not be based on direct observations of actual learners. Instead, the analysis is essentially of the innovation itself and is based on the comparison of the hypothetical behavior of learners with and without the innovation.

2. Quasi-experimental empirical work: Second, we wanted our framework to be useful for cases in which we have direct observations of people engaged in learning interactions both with and without scaffolding. In this case, the analysis would be based on a comparison of the two sets of observations.

3. Descriptive empirical work: Finally, we wanted our framework to aid in analysis when we have direct observations of certain learning interactions but not of any comparison situation. To perform the analysis of scaffolding in this case, we would construct our analysis around hypotheses concerning how learners would interact in a comparison situation.

In attempting to encompass all of these cases, we are being very inclusive. We have set out to define an analytic framework that is useful for designers as they reflect on the rationales behind their design. We also want a framework that can be used by behavioral scientists as they attempt to understand learning interactions across real-world settings, designed instructional interactions, and carefully crafted laboratory situations.

A New Framework

The previous discussion implies that any statements we make about scaffolding are relative to the particular framework within which we situate the analysis. Because of this dependence on the framework adopted, we believe that when we need to be precise, it is best not to talk about scaffolds and scaffolding as entities or even as processes. Rather, it is more precise and useful to speak in terms of a scaffolding analysis.

Figure 2 contains a diagram of our framework for scaffolding analysis. Note that three of the components in the diagram are in boxes: S_{base} , S_{scaf} , and P_{target} . These are the components that we are free to choose in framing a scaffolding analysis. We understand these components of the framework as follows:

- **Scaffolded and base situations:** A scaffolding analysis is defined in terms of a comparison of two situations, S_{scaf} and S_{base} . S_{scaf} is the current learning situation that we are concerned with and that we want to understand in terms of scaffolding. S_{base} is the base or unassisted situation that we chose for comparison. In each case, the situation is defined by elements of the physical and social surround as well as by the knowledge and capabilities of the individuals participating. Δ_s is the difference between S_{scaf} and S_{base} . For example, there may be a calculator or an individual present in S_{scaf} that is not present in S_{base} . This analysis of Δ_s in the situation can be carried out at different grain sizes, with the grain size in part determined by our selection of the target performance.
- **Target performance:** A scaffolding analysis must also specify what we are treating as “the same” across the base and scaffolded situation. In our framework, we understand this as a description of an idealized target performance (P_{target}). In some instances, we may select a target performance that very narrowly specifies the performance we are looking for. As we have seen, in the early scaffolding liter-

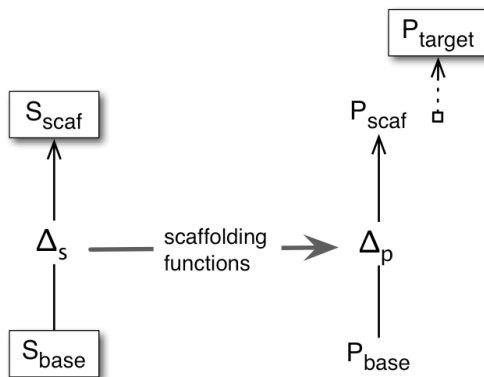


FIGURE 2 Analytic schema.

ature, a strong form of invariance was assumed, one in which the sequence of steps is held constant. More recent literature has relaxed this constraint greatly. It should be noted that P_{target} really serves two functions in a scaffolding analysis: It determines what attributes of performance we pay attention to, and it specifies, in terms of these attributes, the performance that we hope is achieved.

Once the preceding three components of the analysis are specified, the remaining components are determined through observation—either hypothetical or real—of student performance in the scaffolded and base situations.

- Scaffolded and base performances: We want to compare the performance capability of individuals in each of the two situations, P_{scaf} and P_{base} , paying attention to the attributes specified in P_{target} . Note that when the scaffolding is functioning properly, P_{scaf} will match P_{target} .
- Analysis of the functions of Δ_s in enhancing performance capabilities: The scaffolding analysis outputs an account of how the differences between the two situations, Δ_s , function within the system of person and surround to allow the improved performance capabilities, Δ_p .

As a first illustration of the application of this framework, imagine that we are instructional designers, and we are designing an instructional activity in which students will be working on the train problem. Because we are imagining that we are instructional designers, we will be using the framework for the first of our three types of analysis: the construction of a design rationale. To begin this analysis, we can take the scaffolded situation, S_{scaf} , to be the situation in which a student solves the train problem with a calculator, pencil, paper, and the diagram shown in Figure 1. If we wish to construct a rationale for the inclusion of the calculator, we can then choose S_{base} to be a situation that is identical to S_{scaf} except that the student is not given a calculator.

For the target performance, we might choose a moderately strong version of stepwise task invariance; in particular, we might imagine that the sequence of steps is specified up to the level at which specific numerical computations are performed. So, for example, the target performance might specify that 55 will be multiplied by 3, 30 multiplied by 3, and the results added together. However, it would leave open the precise manner in which these individual computations are performed such as using a pencil or using a calculator. A specification of P_{target} would probably also include some other attributes beyond a simple sequence of steps. For example, it should probably include some idea of how rapidly we expect these steps to be performed. If the solution takes hours, this is far from ideal even if the solution is accurate. These choices for S_{base} , S_{scaf} , and P_{target} , which frame the scaffolding analysis, are summarized in Table 2.

TABLE 2
 Framing for a Scaffolding Analysis of a Situation in Which a Student Works
 on the Train Problem

S_{scaf} :	The student solves the Train Problem with a calculator, pencil, paper, and the diagram shown in Figure 1
S_{base} :	Identical to S_{scaf} except that the student is not given a calculator
P_{target} :	The sequence of steps is specified up to the level at which specific numerical computations are performed

Note. S_{scaf} = scaffolded situation; S_{base} = base or unassisted situation used for comparison; P_{target} = target performance.

The differences between S_{base} and S_{scaf} are clear, at least in crude terms. The key difference is the presence of the calculator. The description of differences in performance is the heart of the analysis and where the analysis becomes difficult. As instructional designers, we must justify our decision to include the calculator in our design based only on hypotheses about the impact of Δ_s on the performance of learners in our target population. For example, we might hypothesize that in S_{scaf} , the student may progress more rapidly through the sequence of steps that are specified in P_{target} . More dramatically, absent the support provided by the calculator, we might believe that students would fail to complete the sequence of steps.

The heart of our design rationale is an account of how the particulars of Δ_s —in this case, the presence of the calculator—function to allow the changes in performance capability. This rationale consists of an analysis of the function of the calculator of the form suggested by Cummins (1999): The analysis describes how the calculator will function within the system that consists of the student and other elements of the situation to help the students to produce a sequence of steps, P_{scaf} , that more closely approximates those specified in P_{target} . For example, we might argue that the calculator functions to allow this improved performance because it takes over some of the steps in the solution, perhaps freeing up cognitive resources.

In addition to using the framework in the construction of a design rationale, we envision using it to guide analyses in quasi-experimental or descriptive empirical work. For illustration, we consider a program of quasi-experimental work involving the train problem. In that type of work, we could set up a comparison in which we look at students in S_{base} and S_{scaf} . (These might be the same students or two groups of students.) Rather than only speculating about performance differences across these two situations, we would look, empirically, for differences in performance along the dimensions picked out by P_{target} . (In this case, the P_{target} we selected specifies a sequence of steps for us to compare against.) We would then look for evidence concerning how the scaffolding artifacts function. For example, we might look simply to see whether the students use the calculator when it is available, and we might compare the amount of time required for computations when the calculator is and is not present.

Why We Excluded the Assumptions in Observation 3 From Our Framework

Earlier, we presented a list of observations concerning how scaffolding has been implicitly defined in the past. Some of these implicit features of past definitions were incorporated in our framework. Our framework includes the idea that there is a comparison between assisted and unassisted situations and that there is a task that is held constant across these situations. However, our framework does not include the features discussed in Observation 3. In that observation, we attributed two assumptions to earlier research on scaffolding: (a) the task that is held constant is an expert task and (b) the support will gradually be faded until the novice is able to perform the expert task without support.

The case for excluding assumption (a) is comparatively easy to make; indeed, we believe that much of the more recent research on scaffolding has excluded this assumption. As we argued earlier, we believe that adopting this assumption would have the effect of ruling out a substantial fraction of school-based learning activity. Stated briefly, there are important learning tasks that are not expert tasks, and we want to be able to apply our notion of scaffolding to these learning tasks.

Our choice to exclude assumption (b)—that the scaffolding will gradually be faded as the student learns—is potentially more controversial. As discussed earlier, some authors have stressed the extent to which the scaffolding process is dynamic (e.g., Stone, 1998a). Over the course of hours, minutes, or even seconds, tutors adapt the support provided to a learner as the learner's capabilities change over time. For authors concerned with understanding this dynamic process, the analytic goal goes beyond an understanding of the scaffolding function of any particular element of the situation. These authors want to understand the dynamics of the unfolding process, especially how scaffolds are selected and calibrated during the interaction.

In contrast, an analysis based on our definition will not address the dynamics that lead to such changes in scaffolding. The framework in Figure 2 provides a schema that allows us to understand how particular fixed elements of a situation can function to change the performance of a given learner in a given situation. However, there is no treatment of an unfolding process or of any change over time.

In excluding any treatment of change over time, we are pruning out some of the most prominent themes that have surrounded prior discussions of scaffolding. For example, our framework does not include a treatment of fading, nor does it provide a way to discuss a movement from other regulation to self-regulation. Most profoundly, our framework provides no obvious way to describe the changes in knowledge and abilities—the learning—of students.

A number of things can be said in defense of this choice. As we stated in the introduction, we have adopted the stance that there is no single right answer to how the notion of scaffolding should be interpreted when applied to the analysis of artifacts. Rather, we set out to design an analytic framework that is useful for our pur-

poses. Therefore, the appropriate question to ask is whether our framework is, in some way, useful. Our hope is that in the remainder of the article, we can begin to demonstrate the utility of our framework. That demonstration is intended to be the heart of our argument for the choices we have made.

However, there are some things that can be said up front in support of the trade-offs we have made. First, we believe that our decision to not include fading is sensible given our focus on the scaffolding of technological artifacts. In the case of technological artifacts, there is less of an opportunity for interactive tuning of scaffolding. Although some researchers have designed software that gives adaptable support (e.g., Guzdial, 1994; Jackson et al., 1998), the extent to which this support can adapt is less than in person–person interaction.

Second, the exclusion of any explicit treatment of learning might seem like a big price to pay. However, we feel that in excluding the dynamics associated with learning, we have gained a lot in terms of simplicity and precision. Our framework is narrowly focused on what we take to be the heart of analyses of scaffolding: an understanding of how differences in support change what is possible at any moment in time.

Finally, our framework has been constructed so that there are some simple steps we can take to include, in a modest way, some of the dynamics of learning and fading. In a later section, we return to these issues, and we briefly discuss how our framework can be extended to capture some of these dynamics.

Prototypical Types of Scaffolding Analyses

The analytic framework presented previously was extremely general, and it permits instances of analysis that do not produce useful or even sensible results. This means that our framework, to be useful, needs to be fleshed out with additional guidelines and heuristics.

Notice that the scaffolding analysis framework shown in Figure 2 can be thought of as a schema consisting of slots corresponding to the labeled elements of the diagram. When the slots of this schema are filled with a given set of defaults, then we have a specification for a prototype variety of scaffolding analysis. For illustration, consider the analytic scheme that was implicit in the earliest discussion of scaffolding. As we have discussed at some length, the notion of scaffolding was originally developed to describe a situation in which a child or student is assisted by another individual. We would describe this as a prototype schema with the following fillers:

The expert–novice tutorial dyad:

S_{base} : The novice works alone on a task. This task is extended in time and has multiple discrete steps. Furthermore, the task generally involves the manipulation of some aspect of the physical environment.

S_{scaf} : The novice works on the same task but in the presence of an expert. The expert gives verbal guidance and may also directly intervene in the physical aspect of the task, taking over some of the components specified in P_{target} .

P_{target} : In the purest form of this prototype, P_{target} consists of a fixed set of component steps.

This is the form that our heuristic guidance takes; in the remainder of this section, we present a nonexhaustive list of prototype varieties of scaffolding analysis, each of which corresponds to a default set of fillers for our scaffolding schema. More specifically, we describe configurations of choices for S_{base} , S_{scaf} , and P_{target} because as mentioned previously, these are the parameters that we are free to choose in constructing a scaffolding analysis.

Technological tool versus no tool. We now move to the prototypes that are of particular interest in this article, those concerned with the scaffolding provided by external artifacts, especially technological artifacts. We begin with a crude scaffolding analysis, one in which an entire technological tool is either present or not present.

S_{base} : An individual does a task without an artifact.

S_{scaf} : An individual does a task with an artifact. The artifact is a single, recognizable physical object.

P_{target} : This will vary significantly depending on the nature of the tasks involved. It might take the form of a set of task components, some of which might be performed by the artifact. In other instances, performance might only be judged with regard to a particular external product.

One of our example scaffolding analyses in which a student solves the train problem with and without a calculator, closely fits this prototype. As we discussed earlier, we can see the calculator as essentially performing some parts of the solution of the train problem, with the rest remaining relatively unaltered.

Expert or generic artifact versus learning artifact. Another useful prototype can be developed by considering the case in which a designer begins with an expert tool and modifies the tool so that it is adapted for use by learners.

S_{base} : A student works alone or with a small number of other students using an expert tool. The task performed is a version of an expert task that has been adapted for classroom use. (Note that this task adaptation is included in S_{base} .)

- S_{scaf} : A student works on a task that is largely the same but uses a version of the tool adapted to the needs of learners.
- P_{target} : In some cases, the components of the task may be largely specified. However, in some cases, P_{target} might only loosely constrain the task components; it might even only describe the product that is to be produced by the student. (For example, it might specify that the goal is to produce an explanation of some phenomenon.) Furthermore, the learner-adapted tool may add substantial subtasks that are not part of the task when it is performed with the generic tool (even for the adapted version of the expert task).

There are many possible ways that features of learner-adapted artifacts can function to alter performance capabilities. For example, the learner-adapted artifact may simply lack features that are present in the expert tool, thus helping to constrain the activity of the learner. Alternatively, the artifact might include built-in coaching that gives advice to the learner or might have features that explicitly communicate the steps to be taken.

It is here that we can see the bridge between the early scaffolding literature and some of the more recent applications of scaffolding to educational technology. Recall that one of the original grounding notions of the scaffolding metaphor was the idea that learning happens best in the context of actually performing tasks that are characteristic of expertise. If we accept this idea, then it seems sensible to engage students in the use of expert tools even if we believe that the constraints of schooling require that the tools must be somewhat adapted for use by learners.

We intend this prototype to cover two important subcases. In the first narrower case, the expert tool is specifically designed for experts in the discipline under study by students. For example, chemists employ software that lets them visualize the structure of molecules. We can imagine adapting such software and making it available to chemistry students (Beckwith & Nelson, 1998). We also have in mind the adaptation of more generic tools—such as word processors, databases, spreadsheets, and Web browsers—that are employed across a range of disciplines. One could modify these generic tools with specific supports that help learners manage complexity within the particular discipline under study. For example, the Knowledge Integration Environment (Bell & Linn, 2000; Linn, 2000) scaffolds learners by building curricular and technological supports around Internet sites. A number of programming languages have also been developed with the needs of learners in mind. These include Logo (Papert, 1980), StarLogo/T and NetLogo (Resnick, 1994; Wilensky, 1997), Boxer (diSessa, 2000; diSessa, Abelson, & Ploger, 1991) and AgentSheets (Repenning, 1993).

Learning artifact versus scaffolded learning artifact. Sometimes it is most revealing to construct an analysis in which a learning artifact provides its own

base situation. In these analyses, one constructs a scaffolding analysis by imagining additions, deletions, or other transformations to the learning artifact. For some learning artifacts, this is the only type of scaffolding analysis that is possible. This is the case for learning artifacts for which there is really no expert analog or for which any expert analog differs dramatically from the learner-adapted tool. Computer modeling tools such as Model-It™ (Krajcik et al., 1998) are of this sort. Other examples include the powerful environments that have been developed for dynamic geometry (Geometer's Sketchpad™; Jackiw, 2001; Cabri™; Laborde & Laborde, 1995) and for biology (Genscope™ and Biologica™; Hickey, Kindfield, Horwitz, & Christie, 1999). The schema for this prototype is as follows:

- S_{base}: An individual or group works on a task with a learning artifact.
- S_{scaf}: An individual or group works with a learning artifact that has been augmented with additional features or otherwise transformed.
- P_{target}: In some cases, the components of the task may be largely specified. However, the transformed tool may add substantial subtasks.

We believe that some extant analyses in the literature can be profitably understood as analyses based around this prototype. For example, Guzdial (1994) described an environment called Emile that scaffolds students in the programming of simulations of motion. In this article, Guzdial (1994) presented a systematic analysis of the types of support provided in Emile, essentially taking the rest of Emile as backdrop for each component of the analysis. There are three main categories of support identified: (a) "communicating process," (b) "coaching," and (c) "eliciting articulation." Furthermore, each of these categories is linked to specific features of the software. Analyses of this sort could, we believe, be recrafted so that the features are understood as Δ_s , and the categories of scaffolds become analyses of the functions of these features.

Compound learning artifact prototypes. When looking at learning artifacts, it will rarely be the case that we are only concerned with a single element of the artifact and the scaffolding functions of that element; rather, we are concerned with an ensemble of candidate elements. Ultimately, we need to understand how our prototypes can be extended to cover these more complex—and more realistic—circumstances. Here we illustrate what might be done by considering two kinds of extensions to the preceding learning artifact prototypes. In these extensions, we essentially form compound prototypes by performing two parallel scaffolding analyses.

First, consider the case in which we have two candidate elements that we are considering as alternative ways to perform a single scaffolding function. In that case, we can set up two parallel scaffolding analyses—we call them *Analysis A* and

Analysis B—based around these two candidates. As shown in Table 3, S_{base} and P_{target} are the same across these two parallel analyses; only S_{scaf} differs. Analysis A includes candidate element a in S_{scaf} , and Analysis B includes candidate element b . For each analysis, we are concerned, as usual, with P_{scaf} and how the proposed element functions to allow any improvements in performance. In addition, this prototype must include the extra step of comparing the results across these two parallel analyses.

There is another, more complex, case to consider. In some situations, a technological artifact may have many elements that are intended to perform scaffolding functions while operating in parallel. Our framework offers the possibility of dealing with this complexity in multiple ways. We could choose to look at many elements together within a single scaffolding analysis, grouping them all within Δ_s . In that case, we would perform our scaffolding analysis according to one of our original learning artifact prototypes. Alternatively, we could look at each of the elements within a separate scaffolding analysis, holding the other elements fixed. Each of these two approaches has merits and embodies trade-offs. For example, treating the elements separately might allow for a more focused analysis but at the expense of missing synergies that are only apparent when elements are treated in combination. Table 4 lays out a compound prototype for one possible structuring of an analysis in which we look at what happens when individual elements are removed from a learning artifact. The new prototype can be understood as involving parallel scaffolding analysis in which S_{scaf} and P_{target} are the same, but S_{base} differs.

How to Choose S_{base}

In this section, we emphasize one additional guideline for the construction of a scaffolding analysis: A scaffolding analysis is only sensible if S_{base} does not differ too

TABLE 3
A Compound Prototype That Frames an Analysis in Which Two Candidate Elements are Considered for the Same Scaffolding Function

<i>Variables</i>	<i>Analysis A</i>	<i>Analysis B</i>
S_{base} :	An individual or group works on a task with a learning artifact	An individual or group works on a task with a learning artifact that is the same as in Analysis A
S_{scaf} :	An individual or group works with a learning artifact that has been augmented with additional element a	An individual or group works with a learning artifact that has been augmented with additional element b
P_{target} :	This is the same across the two parallel analyses	This is the same across the two parallel analyses

Note. S_{base} = base or unassisted situation used for comparison; S_{scaf} = scaffolded situation; P_{target} = target performance.

TABLE 4
A Compound Prototype for a Case in Which Multiple Elements are Acting
in Tandem^a

<i>Variables</i>	<i>Analysis A</i>	<i>Analysis B</i>
S_{base} :	An individual or group works on a task with a learning artifact; the artifact includes features <i>b, c, d, e</i> , and so forth, but not feature <i>a</i>	An individual or group works on a task with a learning artifact; the artifact includes feature <i>a, c, d, e</i> , and so forth, but not feature <i>b</i>
S_{scaf} :	An individual or group works with a learning artifact that has been augmented with all features <i>a, b, c, d, e</i> , and so forth; this is the same across the parallel analyses	An individual or group works with a learning artifact that has been augmented with all features <i>a, b, c, d, e</i> , and so forth; this is the same across the parallel analyses
P_{target} :	This is the same across the two parallel analyses	This is the same across the two parallel analyses

Note. S_{base} = base or unassisted situation used for comparison; S_{scaf} = scaffolded situation; P_{target} = target performance.

^aThis prototype frames an analysis in which one element is removed at a time.

much from S_{scaf} . If the situations differ dramatically, then we end up with an analysis in which the Δ s are extremely large and P_{target} only weakly specifies the performance. This, as we argue here, leads to a scaffolding analysis that is not revealing.

Many analyses in the literature have implicitly made choices for S_{base} and S_{scaf} that we believe are appropriate; they have constructed their analyses so that S_{base} is appropriately close to S_{scaf} . In one such instance that was mentioned previously, Guzdial (1994) described an environment called Emile that scaffolds students in the programming of simulations of motion. In another instance, Krajcik, Jackson, and colleagues have discussed the scaffolding provided by a computer modeling environment called Model-ItTM (Krajcik et al., 1998) and its descendent TheoryBuilder (Jackson et al., 1998), which guide students in the construction of dynamical system models.

In both of these cases (Guzdial, 1994; Jackson et al., 1998; Krajcik et al., 1998), the authors were asking students to engage in tasks that differ radically from the tasks that are given in more traditional science instruction; they dramatically altered the representational tools that are used and the products that students are asked to produce. In these cases, we believe it would not be useful to choose as S_{base} the case in which a student works on a traditional science task. Instead, a more appropriate analysis would work within the given computer tool and consider the addition and deletion of features from this tool.

This is precisely the approach taken by both of these research teams. For example, Jackson et al. (1998) discussed the scaffolding associated with the addition of features such as reminder messages that appear automatically as the students make

their models. Such a message might point out, for instance, that a student was proceeding to the next phase of the task without completing the current phase. In talking about this feature as a scaffold, Jackson et al. were implicitly taking, as S_{base} , the situation in which a student makes use of the same modeling software but without reminder messages (or with the messages turned off, as the software allows).

There is a general point here that deserves additional emphasis. We believe that when we design new representational tools for students and we design entirely new versions of tasks, we must be very careful in constructing scaffolding analyses of these tools and tasks. Analyses that consider small Δ s and consider variations on the use of a given tool will make sense, but scaffolding analyses that try to compare these new situations with more traditional activity will likely not be productive.

Returning to the historical roots of scaffolding, particularly in the work of Vygotsky (1978), provides us with another way to make this point. According to Wertsch (1985), one of the most important contributions of Vygotsky was the notion of mediation. Vygotsky (1978) began with Engel's notion of instrumental mediation as it applies to "technical tools" and extended this notion to cover psychological tools or "signs." Furthermore, higher mental functions were seen by Vygotsky (1978) as first arising in the interpsychological plane and then on the intrapsychological plane. It is the mediation of signs that makes this possible.

Thus, the shift to a focus on the scaffolding associated with external artifacts is a shift that is somewhat consonant with these early roots in Vygotsky's (1978) work. However, at the same time, the recognition of the relation of scaffolding to mediation adds additional weight to the cautions we raise in this section. For Vygotsky (1978), the mediation of signs is an ever present and fundamental attribute of human thinking.⁴ If we believe this, then it is clear that a change in symbolic artifacts can fundamentally change the nature of tasks and the nature of the reasoning involved.

We do not believe that these observations should be discouraging to designers of complex computer environments that involve designed scaffolds. Quite the contrary is true. We believe that the software design community should, at least sometimes, see itself as doing real creative work that cannot always be understood in terms of small changes to existing learning situations. When this is the case, certain kinds of scaffolding analysis will simply not be sensible. When we dramatically change the material resources available to people, especially in the form of new representational means, there will in general be no straightforward way to understand the functions of these resources with respect to the changing of the capacities of individuals.

⁴We are grateful to one of our anonymous reviewers for help in making this connection to mediation.

SAMPLE APPLICATIONS OF THE DEFINITION

In this section, we present two extended examples of scaffolding analyses that make use of the preceding definition. These examples are intended, in particular, to illustrate two of the learning artifact prototypes described previously. The first example illustrates the *expert artifact versus learner artifact* prototype through an analysis of the WorldWatcher (Edelson, Gordin, & Pea, 1999) environment. The second example illustrates the *learner artifact versus scaffolded learner artifact* prototype through an analysis of a software tool called ExplanationConstructor. In both cases, our analysis is intended to show how our framework can help in framing a design rationale rather than how it can help in framing empirical work involving observations of learners.

Scaffolding Analysis Example: WorldWatcher

WorldWatcher (Edelson, Gordin, & Pea, 1999) is a visualization and analysis tool developed for middle school, high school, and college students. It was designed to replicate the functionality of a class of scientific visualization tools that scientists use for analyzing scientific data that is recorded in rectangular arrays (grids) such as temperature or elevation data. Figure 3 shows a data display from a visualization and analysis package that was in wide use in the scientific community at the time

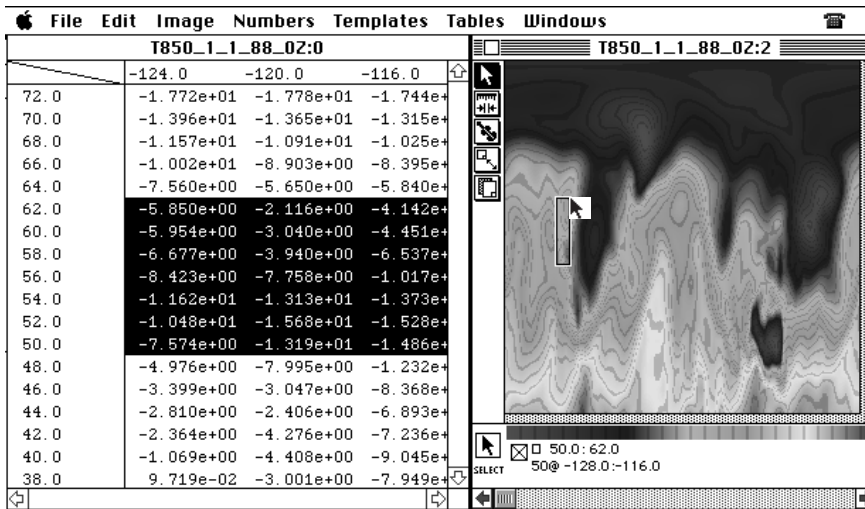


FIGURE 3 A visualization of temperature data for January 1, 1988 for the Northern Hemisphere displayed by Spyglass Transform.

the development of WorldWatcher began. Figure 4 shows a similar data display from WorldWatcher.

WorldWatcher was adapted from expert tools using a number of different strategies (Edelson et al., 1999). In this discussion, we consider three of those strategies:

1. Addition of contextual information to the user interface: The goal of this adaptation was to identify some of the tacit knowledge that scientists use to help themselves interpret visualizations and embed that as contextual information in the user interface. An example is the display of units, latitude and longitude markers, and continent overlays on visualizations.

2. Strategic selection of functionality: In this adaptation strategy, the designers attempted to select a set of data analysis operations that would provide students with significant analytical power without making the user interface too compli-

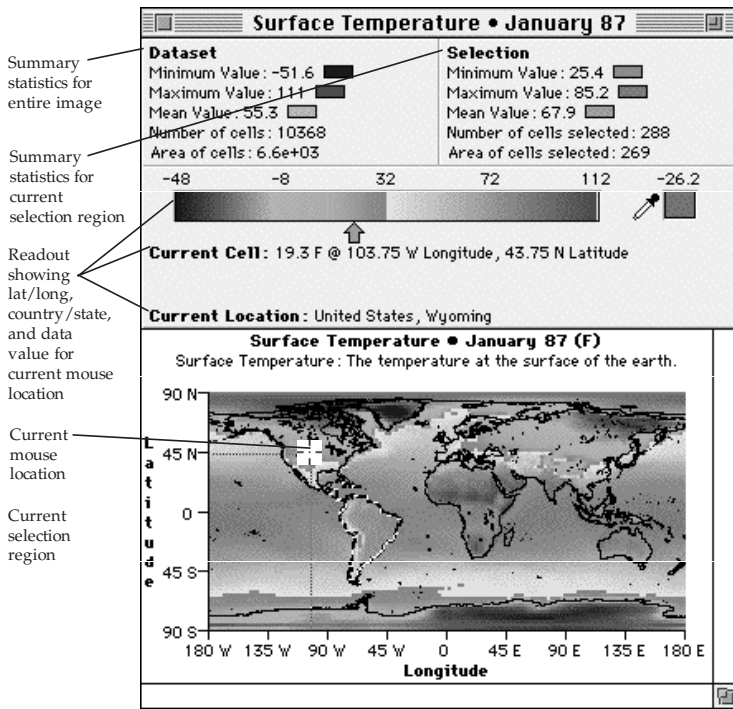


FIGURE 4 A visualization window from the WorldWatcher software displaying surface temperature for January 1987.

cated or overwhelming students with operations that were difficult to perform or understand.

3. Addition of pedagogically valuable functionality: In this form of adaptation, the designers added functions and visual representations that are not found in expert tools but that would enable students to engage in activities that would support learning.

In the following, we attempt to construct a scaffolding analysis for one example of each of the strategies just described. However, for the third strategy, we argue that a scaffolding analysis would not provide useful results. For all of these examples we use, as our context, a set of activities from a middle school Earth science unit. In this unit, students investigate the relations between physical geography and temperature at a global scale (Edelson, 2001). Because these scaffolding analyses represent design rationale, they describe hypothetical learners. They are, however, based on a broad range of experience with real students.

Addition of contextual information to the user interface. The example of this adaptation is superimposing recognizable geographic features and latitude/longitude markings on the gridded colormap representation (Figure 4). The prototype is expert artifact versus learner artifact:

- S_{base} : Using visualizations showing surface temperature and surface elevation, students attempt to identify differences in temperature due to changes in surface elevation. To do this, they use Spyglass Transform, a data visualization and analysis tool designed for scientists.
- S_{scaf} : Students attempt the same task using WorldWatcher. Unlike Spyglass Transform in S_{base} , this includes continent overlays and latitude/longitude markings.
- P_{target} : The task in both situations is to compare surface temperature and elevation data and to induce the relations between these two variables.

We expect certain kinds of differences between P_{base} and P_{scaf} . In P_{base} , students have difficulty identifying regions of interest in the undifferentiated grid of colors (see Figure 3). This is not the case in P_{scaf} ; the students using WorldWatcher are able to quickly identify regions of interest based on their locations within the continent outlines. More students are able to successfully complete the task, and they construct a better understanding of the relation between temperature and elevation.

A scaffolding analysis must say how the differences between S_{scaf} and S_{base} , Δ_s , function to allow this change in performance. As designers, our intention was that these differences would achieve this change by narrowing the work that must be done by learners. In particular, this adaptation is designed to shift learners' efforts from

understanding what portion of the world they are viewing to interpreting the data for that location, with the result that they are able to focus more of their cognitive resources on aspects of the process from which they will learn the intended content.

Strategic selection of functionality. The example of this strategy is the choice to only include a small number of operations for quantitative data analysis and to provide a structured interface for invoking them. Again, the prototype is expert artifact versus learner artifact.

- S_{base} : Using data for surface temperature in January and July, students attempt to identify seasonal differences in temperature by calculating the numerical differences between the data values at each point in the two data sets. To do so, they use Spyglass Transform, and they invoke a powerful general-purpose macro facility that requires them to enter a formula into a blank “notebook” window. In the formula, they must type the name of each data file as the name of a variable and assign a new name to the result of the calculation. To perform the calculation, they must highlight the formula they have entered with the cursor and select “Run macro” from a menu. If they have a typo in their formula, they receive an error message designed for programmers.
- S_{scaf} : Students attempt the same task using WorldWatcher. To calculate the difference, students select “Window Math Operation” from the toolbar or menu. They then complete a structured form by selecting an operation from a list of simple arithmetic operations (+, −, ×, /, average, minimum, maximum), then selecting each of the data sets from a list of available data, and finally typing in a name for the result of their calculation.
- P_{target} : Students correctly, and relatively rapidly, subtract July surface temperature from January.

The replacement of a powerful general-purpose facility with a less-powerful, constrained facility enables the software to provide a more structured interface to the operations that remain. The structured interface functions to guide students in the subtraction task, leading to correct execution of the task with less effort. This also enables them to dedicate more cognitive resources to interpreting the resulting visualization showing seasonal differences.

Addition of pedagogically valuable functionality. The example of this adaptation strategy is that WorldWatcher includes a “paint” tool that allows users to construct new data sets or modify existing data sets using a conventional paint program interface. Users select values to paint in a dataset by clicking on a color in the legend or by entering numerical values from the keyboard. They can then enter that value into individual grid cells or entire regions of the image using the conven-

tional metaphors of paint brushes of different sizes and paint cans. This functionality does not exist in professional visualization and data analysis tools. It was added to WorldWatcher to support a class of activities in which students express their theories about phenomena by creating visualizations.

Because there is no comparable activity that is supported by the expert tool, it is not clear how to set up a scaffolding analysis that highlights this feature. As we discussed previously, this is a common and important problem. When our learning adaptations are dramatic, scaffolding analysis may cease to be a viable tool. The painting capability is clearly a support for learning, but it may just not be helpful to understand this support through a scaffolding analysis because there is no sensible base situation for comparison.

Scaffolding Analysis of an Argument Support Tool

In this section, we look at a software tool, ExplanationConstructor, that is designed to support students' articulation as they engage in scientific investigations (Reiser et al., 2001; Sandoval, 2003). ExplanationConstructor is designed to work in concert with software investigation environments, and it provides a structure in which students can record their emerging arguments including the research questions, candidate explanations, and backing evidence for these explanations. Here we focus on the use of ExplanationConstructor in tandem with a particular investigation environment, Galápagos Finches (Reiser et al., 2001; Tabak, Smith, Sandoval, & Reiser, 1996).

The Galápagos Finches is an environment that enables learners to investigate changes in a population of plants and animals and is embedded in a curriculum that teaches students about ecosystems and natural selection. At a very broad level, it can be understood as consisting of a database plus a query interface, with the database containing information concerning the population of finches on the Galápagos Islands along with other relevant environmental and population information. The students' task is to use this data to develop and argue for an explanation for why many of the finches in the Galápagos died over a short period of time.

The Galápagos Finches is itself an environment designed to scaffold learners as they engage in their investigation around the data provided in the database. The query interface is specially designed to support learners' reasoning about populations in ecosystems; it provides structures for learners beyond a more generic database system. However, our analysis here focuses on the additional support provided by the ExplanationConstructor; we compare hypothetical students working with the Galápagos Finches alone to students working with the combination of Galápagos Finches and ExplanationConstructor. Thus, the scaffolding analysis we present is an instance of the prototype learning artifact versus scaffolded learning artifact. To not repeat and belabor points that have already been made, our discussion here is briefer than our discussion concerning WorldWatcher.

ExplanationConstructor combines a specially tailored outlining tool used to articulate questions, subquestions, and associated questions and a simple word processor used to construct explanations (refer to Figure 5). As the investigation proceeds, students articulate and revise questions and subquestions. When they are ready to encode a candidate explanation, they write out the analysis attached to a question. As they uncover relevant data, they paste it into the list of figures in ExplanationConstructor and cite this evidence as appropriate when writing explanations. Our brief scaffolding analysis is as follows:

- S_{base}: Students use Galápagos Finches alone to investigate the problem scenario. When it is time to prepare a final report, students may decide to print out relevant data displays. Students use a generic word processor to write out their explanation and may refer to the data displays in their text.
- S_{scaf}: Students use Galápagos Finches along with ExplanationConstructor, articulating questions and explanations with associated evidence.
- P_{target}: P_{target} specifies the product of the task, namely, the construction of an explanation about what has happened to the population of finches on the

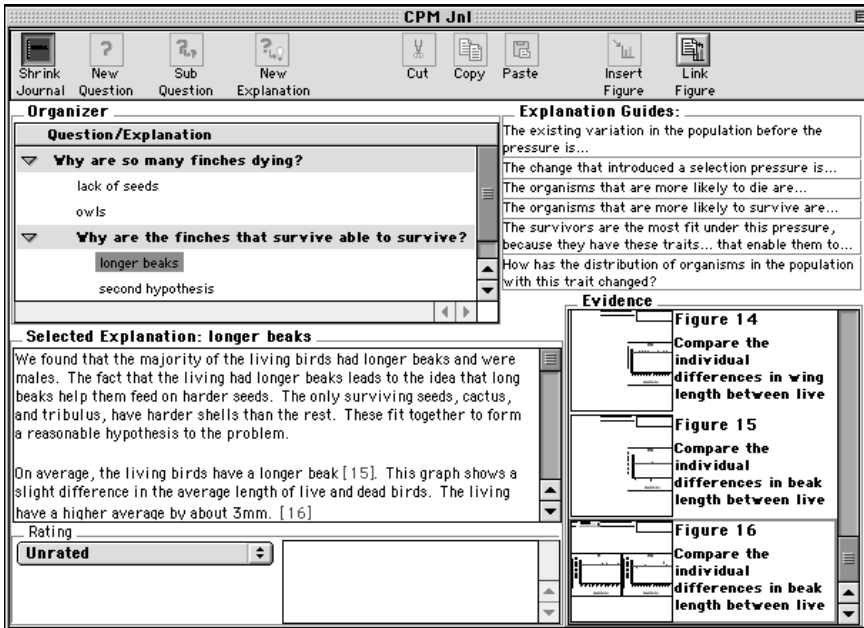


FIGURE 5 A sample session with ExplanationConstructor.

island. We can also include components of the investigation process in P_{target} . In both situations, students will be trying to navigate the database and assemble evidence, with this navigation driven by the emerging explanation that is being constructed.

The Δ_s is the inclusion of the particular features of ExplanationConstructor: the outlining tool, guiding questions, and mechanisms for pasting and linking evidence. Because of the extent of these differences, we expect to see a number of differences between P_{scaf} and P_{base} . These expected differences include the products of the investigation; we expect to see more fully fleshed-out explanations in which students have addressed more of the core constituents of a population change explanation (represented in the guiding questions). We expect to see more alternative explanations represented and greater use of backing evidence to support claims. Finally, we expect a more precise correspondence between evidence and assertions. (In unscaffolded work, students are vague about what evidence backs which part of their argument and why the evidence supports each claim.)

All of these improved outcomes should be reflected in changes in aspects of the investigational process along dimensions picked out by P_{target} . For example, we expect to see more consideration of alternatives and evidence within investigation groups. Furthermore, these considerations should drive students as they move through the data, helping them to navigate in a more effective manner.

The analysis of scaffolding functions in this case is complex. ExplanationConstructor is a substantial addition to the Galápagos Finches; it might well push the limits of what can be productively treated by a single scaffolding analysis. Roughly speaking, the Δ_s provided by ExplanationConstructor can be understood as multiple representations of various kinds of epistemic structures. These representations of epistemic structures help guide students in their investigation and help them as they refine their explanations. For example, the outline provides a broader framework for what must be explained. This can have the function of guiding students in their explanation at the more broad, procedural level.

Other aspects of Δ_s provide a more fine-grained representation of the epistemic structure of the explanation. The representation is more transparent than simple expository text; it reveals the underlying structure of an argument in terms of its questions, subquestions, and competing explanations for each question. The representation thus makes it more clear, for example, whether students have attached multiple explanations to a question and whether some questions are lacking explanations. Thus, particular features of the representational display have the function of prompting students to reconsider and refine explanations and to go back to the data as necessary.

Reflection on the Two Examples

In the example analyses of WorldWatcher and ExplanationConstructor, our template and prototypes only provided a rough guide for the construction of a scaffolding analysis. Clearly, much work remains to be done, particularly in our analysis of functions. Nonetheless, the template and prototype were helpful. Most important, the explicit construction of a framework clarified many aspects of the scaffolding analysis that might otherwise be puzzling. For example, our approach does away with some potential arguments about which features of ExplanationConstructor and WorldWatcher are or are not scaffolds. It does so, first, by making explicit that our determination of scaffolding depends on our choice of comparison framework. In addition, our framework suggests that some features of environments can probably not be treated productively within a scaffolding analysis.

There was one way in which our analyses in this section were simplified. Both WorldWatcher and ExplanationConstructor are complex, and they both have many elements that could potentially be treated as scaffolds. However, our analyses here were based only on independent scaffolding analyses. A more careful treatment should probably involve the construction of a unified analytic frame based around compound prototypes of the sort we discussed earlier.

EXTENDING THE FRAMEWORK TO CAPTURE CHANGE OVER TIME

As we discussed earlier, we believe that the most controversial attribute of our framework will be that it does not capture the dynamics of scaffolding and thus includes no explicit treatment of fading or learning. Although we recognize the importance of both of these dynamic processes to understanding the design and impact of scaffolds, we believe that the analytical framework we presented here, which describes scaffolding as a static feature of a learning interaction, is a helpful first step.

Furthermore, although our discussion must be very preliminary, we can outline how an analysis of dynamics can begin to be layered onto the analytic framework we introduced in Figure 2. First, it is possible that a student's performance might change even if there are no changes in S_{scaf} . In particular, the scaffolded performance, P_{scaf} , may come to better approximate P_{target} because the student learns. Using the sort of diagram presented in Figure 2, this change could be represented as a series of our static diagrams, with P_{scaf} moved successively higher (refer to Figure 6). Similarly, P_{base} could rise so that a student's performance would be better in the absence of scaffolding. We can also understand fading as a series of diagrams in which S_{scaf} is moved progressively closer to S_{base} .

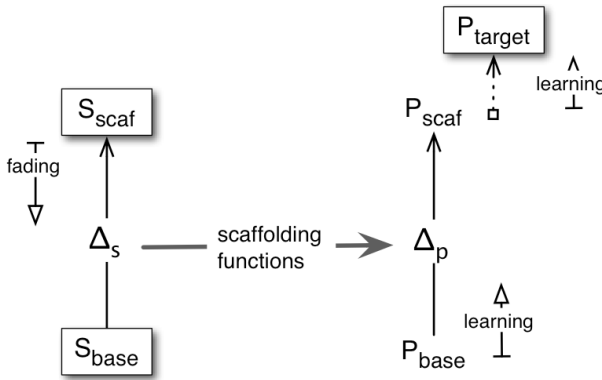


FIGURE 6 Analytic framework with some dynamics indicated.

Clearly the description of these dynamic processes will require more analytical machinery than this initial framework can provide. We view the extension of the framework to dynamic processes as an important area for future work. However, even in the future, we believe that it might be a mistake to try to subsume too much of these dynamics within any discussion of scaffolding. We do want a notion of scaffolding that is appropriately encompassing. However, we will have failed if scaffolding becomes synonymous with the full problem of understanding the dynamics of human interaction.

CONCLUSION

The purpose of this article has been to develop a new analytic framework to guide scaffolding analyses, with a particular emphasis on situations in which learners interact with designed artifacts. This new framework took the form of an analytic template in which the situation to be analyzed, S_{scaf} , is compared to another situation, S_{base} . The effect of this comparison is to highlight some features of S_{scaf} . We then ask how these features function to enhance students' performance in relation to a specified target performance, P_{target} .

It is our belief that this sort of careful design and articulation of theoretical constructs is of great importance in the learning sciences. We anticipate a number of possible ways in which our framework might, after some revision and elaboration, benefit the work of our community. First, one goal of learning sciences research is the development of a body of wisdom about the design of learning environments. We want a tool kit of ideas and design principles along with some account of why these ideas and principles work. However, pooling design wisdom in this way poses great challenges. The hope is that making more of our assumptions explicit,

as advocated in our framework, will help designers to talk to each other and to reconcile their various insights.

Our framework may also provide some guidance in the structuring of empirical work around our designs. The framework suggests a particular empirical approach: Pick relatively small elements for focus and look for changes in performance along particular dimensions when these elements are changed. The results would then take the form of an understanding of how specific kinds of scaffolds function to enable certain changes in outcomes within the context of a particular design.

Empirical guidance of this sort is potentially of great importance given the current climate in educational research. Increasingly, there has been a call for the documentation of results through controlled experiments that compare one instructional condition to another. Our framework does not necessarily argue against the use of experimental methods of this sort, but it does have implications for how these experiments should be conducted and their results understood. For example, it can help us to categorize the various types of comparisons that we set up. Our framework also suggests reasons for caution. It suggests that comparisons might cease to be useful when the compared situations differ too greatly.

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