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Synergy: A Complement to Emerging Patterns of Distributed Scaffolding

Iris Tabak
Department of Education
Ben Gurion University of the Negev, Beer Sheva, Israel

In this article, I examine *distributed scaffolding*, an emerging approach in the design of supports for rich learning environments intended to help students develop disciplinary ways of knowing, doing, and communicating. Distributed scaffolding incorporates multiple forms of support that are provided through different means to address the complex and diverse learning needs that arise in such settings. I synthesize research to date to articulate three patterns of distributed scaffolding and the pedagogical considerations that they target. I introduce *synergy* as a pattern that has not received much attention in the past. Synergy refers to the characteristic that different components of distributed scaffolding, such as software supports and teacher coaching, address the same learning need and interact with each other to produce a robust form of support. I illustrate this pattern through classroom examples and discuss the scaffolding functions that it can fulfill. I conclude with implications for the principled design of distributed scaffolding.

Over the last few decades, there has been a shift from conceiving schooling as the simple acquisition of knowledge and skills to the appropriation of disciplinary ways of knowing, doing, and communicating (Bransford, Brown, & Cocking, 2000; National Council of Teachers of English, 1996; National Council of Teachers of Mathematics, 2000; National Research Council, 1996). For example, we expect students and teachers to work together in transforming knowledge (Scardamalia & Bereiter, 1991) and that understanding the criteria for elegant solutions will be as essential to this process as actually deriving the solutions (e.g., Lampert, 1990; Yackel & Cobb, 1996). This shift coincides with numerous research initiatives that have orchestrated a collection of specially designed materi-

Correspondence and requests for reprints should be sent to Iris Tabak, Department of Education, Ben Gurion University of the Negev, P.O. Box 653, Beer Sheva, Israel 84105. E-mail: itabak@bgumail.bgu.ac.il

als, activities, instructional strategies, and participant structures to cultivate such learning (Bransford, Zech, et al., 2000; Brown et al., 1993; Edelson, Gordin, & Pea, 1999; Krajcik, Blumenfeld, Marx, & Soloway, 2000; Lehrer & Schauble, 2000; Linn & Hsi, 2000; Palincsar & Magnusson, 2001; Puntambekar & Kolodner, 1998; Reiser et al., 2001; Snir & Smith, 1995; White, 1993).

For example, some efforts in science education to support students' development of conceptual models have advanced the efficacy of combining investigations using computer-based simulation environments with whole class discussions (Snir & Smith, 1995; White, 1993). The computer-based environments render normally invisible processes visible, enabling students to attend to features of the phenomenon that distinguish scientific from lay conceptions. The whole-class discussions enable the teacher to explicate the demands of constructing scientific laws and to synthesize ideas across groups to reach consensus and approach normative views. Other initiatives have discussed how the inclusion of benchmark lessons or staging activities, which introduce relevant content and skills, can promote reflective inquiry in subsequent complex investigations, which in turn are supported through scaffolding provided within computer-based investigation environments (Edelson et al., 1999; Krajcik et al., 2000; Reiser et al., 2001).

Puntembekar and Kolodner (1998, in press), have coined the term *distributed scaffolding* to refer to such instructional designs that sequence and integrate a variety of social and material supports. This term builds on the more familiar term, scaffolding. *Scaffolding* refers to the titrated support that helps learners learn through activity. It helps learners perform tasks that are outside their independent reach and consequently develop the skills necessary for completing such tasks independently (Rogoff, 1990; Wertsch, 1979; Wood, Bruner, & Ross, 1976). Other forms of educational or instructional support that provide information or clarify a concept but that do not support performance as well as learning are not considered scaffolds. For example, an encyclopedia might support learning, but it does not support performance, and therefore, it is not considered a scaffold (Guzdial, 1994). Consequently, distributed scaffolding refers to a collection of material and social supports that enable learners to learn disciplines such as science or mathematics by "doing and talking science" or "doing and talking mathematics."

Distributed scaffolding has been adopted (although not necessarily using this term) by a number of researchers over the last two decades and appears to be an emerging practice among researchers interested in supporting inquiry-based science learning (Edelson et al., 1999; Krajcik et al., 2000; Lehrer & Schauble, 2000; Puntambekar & Kolodner, 1998; Reiser et al., 2001; Snir & Smith, 1995; White, 1993). This approach shows promise for cultivating meaningful complex learning (Palincsar & Magnusson, 2001; Puntambekar & Kolodner, 1998, in press; Stratford, Krajcik, & Soloway, 1998; White & Frederiksen, 2000). Yet, there are many questions that remain only partially understood concerning the nature of distributed scaffolding. I address two of these in this article.

One question is whether a collection of instructional materials, instructional strategies, and activity structures can be considered scaffolding. Initially, the scaffolding metaphor had been used to describe the support provided by an adult to a child while working together on a task. Since then, scaffolding has been used to describe additional forms of support and contexts of interaction. This liberal use of the scaffolding metaphor has been contested recently (Meyer, 1993; Puntambekar & Hubscher, in press; Stone, 1998a). Therefore, in the next section, I first defend the idea that support that is distributed among multiple participants and artifacts is congruent with the initial case example in which the scaffolding metaphor was conceived and with the theoretical principles that motivated the use of this metaphor.

Although I claim that the idea of distributed scaffolding is consistent with these original conceptions, I believe that there is value in coining this new term. The connotation to the early uses of the term scaffolding, predominantly in relation to parent–child interactions, might lead one to associate this term with a single means of support. The notion of multiple supports is not inherent to the term and thus leaves these considerations as tacit options for designers. In contrast, the term distributed scaffolding makes these considerations explicit. I propose that invoking the new term can advance current design and research efforts by directing attention to marshaling and orchestrating multiple resources to support learners and to understanding how these resources interact.

This raises the second question I address in this article: How can we approach the design and analysis of distributed scaffolding in a principled way? What ideas underlie this approach beyond the recognition that multiple supports are involved? I take some first steps in formalizing distributed scaffolding by articulating a framework that delineates the different forms or patterns that distributed scaffolding can take and the functions that these different patterns perform. Such a framework can guide future design efforts making distributed scaffolding a purposeful goal. The proposed framework consists of three complementary patterns of distributed scaffolding: differentiated scaffolds, redundant scaffolds, and synergistic scaffolds.

Although some of these patterns have been previously described, there has been no explicit discussion and labeling of all three patterns as constitutive patterns of distributed scaffolding. *Differentiated scaffolds* is a term I am suggesting for a design approach that has been previously discussed and employed in a number of recent research projects. It has been presented as a way of combining multiple forms of support that are provided through different means to address diverse learning needs (e.g., Krajcik et al., 2000). *Redundant scaffolds* has been explicitly identified as a design strategy for distributed scaffolding. It involves different means of support that target the same need but are enacted at different points in time in the curriculum to provide titrated levels of support (Puntambekar & Kolodner, 1998, in press).

The crux of my discussion focuses on the third pattern, *synergistic scaffolds*, which refers to multiple co-occurring and interacting supports for the same need. This has not received much attention in earlier work. A notable exception is an article by Lehrer & Schauble (2000) in which the authors concluded that the support for the developmental changes in mathematical modeling practices that they observed can be explained by the coconstitution of supports in the curriculum. I propose synergistic scaffolds as an important conceptual tool in understanding how different constituents interact to produce support that is greater than the sum of the constituents. The central question is not whether interaction between supports can occur but how this interaction can come into play and what functions it can serve.

I first address the question concerning the justified use of the distributed scaffolding label. This is followed by a discussion of the three patterns of distributed scaffolding, focusing in particular on the synergistic scaffolds pattern. I describe this pattern and illustrate it with a classroom example and discuss how it contributes to the understanding of distributed scaffolding. My discussion of distributed scaffolding centers on inquiry-based learning in science, specifically, the classroom interaction examples that I present focus on the enactment of a unit designed to cultivate biological reasoning through student-directed investigations. Despite the emphasis on science, in this article, I raise implications that are applicable to a range of disciplines.

SCAFFOLDING AS EMBEDDED IN ARTIFACTS AND DISTRIBUTED

Scaffolding was introduced as a metaphor by Wood et al. (1976) to describe the instructional process that enables novices to carry out tasks that are beyond their unassisted efforts, thus helping them achieve independent task competence (for historical reviews, see Hogan & Pressley, 1997; Meyer, 1993; Stone, 1998a). In early work, the scaffolding metaphor was used in examining parent–child interactions (Wertsch, 1979) as well as teacher–student interactions in formal (Cazden, 1979) and informal or apprenticeship settings (Greenfield, 1984). The adult or more-knowledgeable-other structures the task and assumes some of the responsibility for executing the task, allowing the child or apprentice to focus on particular aspects of the task. This assistance is gradually changed and reduced as the child or apprentice gains independence.

For example, a mother was said to scaffold her child in the task of constructing a puzzle by introducing the strategy of locating the correct location of a puzzle piece in a model picture and mapping the location to the actual puzzle (Wertsch & Stone, 1985). Initially, this strategy was carried out through interactions between the mother and the child. The child asked where a particular piece should be placed. The mother asked the child where the piece was located in the model picture and the child responded by locating the piece in the model. As the task progressed, the child moved from being other regulated to self-regulated. This self-regulation was exhibited by the child ceasing to turn to the mother for assistance and narrating his or her progress by "answering" the mother's unasked question concerning the location of the piece in the model picture. In the context of apprentice weavers in Mexico (Greenfield, 1984), the teachers, the expert weavers, were said to scaffold the beginners by taking over the weaving at points in which more technically difficult weaving was involved. This enabled the beginner weavers to complete the entire process of weaving a cloth.

These early depictions can lead researchers to associate scaffolding with the support provided by a single adult human agent. Yet a number of research endeavors have challenged us to consider an expansive view of scaffolding. For example, the research on "reciprocal teaching" and on "cognitive tools and intellectual roles" (Palincsar & Herrenkohl, 2002) has urged us to consider peers and social roles as scaffolding agents. The proliferation of design and technology in educational research has further encouraged us to consider how software (Guzdial, 1994; Hmelo & Guzdial, 1996; Quintana et al., this issue; Reiser, this issue; Sherin, Reiser, & Edelson, this issue) and other artifacts (Englert, Berry, & Dunsmore, 2001; Palincsar, 1998) can support learners in extending their independent performance and in gaining proficiency in disciplinary practices. A telling testament to the broader views taken on what can be considered under the scaffolding metaphor can be seen in the changes between Cazden's 1988 and 2001 editions of the seminal book on classroom discourse. The new edition (Cazden, 2001), in addition to introducing a chapter devoted to "Talk With Peers and Computers," extends the discussion on scaffolding to explicitly note curriculum—a coherent set of contexts and activities—as a scaffold (pp. 60–71).

Nonetheless, recent work studying the metaphor itself (Puntambekar & Hubscher, in press) rather than the quality and efficacy of particular implementations cautions against unwarranted interpretations of the metaphor (Stone, 1998a, 1998b) and misnomers (Meyer, 1993). Can a tool or an activity be considered a scaffold? The premise of this article is that various instructional materials and activities can be considered scaffolds and that an intentionally designed "package" (Salomon, 1996) of materials and activities can be considered distributed scaffolding. I re-analyze the Wood et al. (1976) example to show that support for this idea can be found even in the case example in which the scaffolding metaphor was coined.

Wood et al. (1976) designed a toy consisting of 21 wooden blocks that combine over six layers to form a pyramid. Children aged 3 to 5 years old interacted individually with an adult tutor in sessions ranging from 20 min to an hour attempting to construct the pyramid. The tutor's aim was to gear her behavior to the needs of each child, helping the child complete the pyramid yet allowing the children to do as much as possible for themselves. In analyzing the tutor's interactions with the children Wood et al. identified several functions of the scaffolding process. One of these functions is recruitment, enlisting interest in the task and adherence to its requirements. Another central function, one that is often used as a shorthand description for scaffolding (e.g., Bruner, 1985), is reducing degrees of freedom such as by taking on some of the constituent acts needed to complete the task allowing learners to perfect the ones that they can manage. If one reexamines the Wood et al. example using a broader timescale (Lemke, 2000) that includes not only the enactment of the Wood et al. puzzle task but also the design of the task, one sees that these scaffolding functions are reified by the materials as well as the tutor.

Wood et al. (1976) went to great lengths to describe the qualities of the wooden puzzle, which was developed by Wood especially for the purposes of the study:

> The top block is a solid square with a circular depression in its bottom. Each remaining layer is composed of 4 equal sized blocks made up of two locking pairs. Each pair fits together by a hole and peg arrangement. When one pair is fitted in the correct orientation, two other half pegs are brought together; the other pair brings together two half-holes. These form the means for connecting the two pairs to form the four piece layer. *The blocks were designed so that all pegs would fit into all holes* [italics added]. In addition to pegs and holes, each four-block layer has a shallow round depression in its base and a matched elevation on top. *These can only be formed by putting the appropriate pairs together in the correct orientation* [italics added], since each block possesses one-quarter of each of these larger connectives. (pp. 91–92)

Wood et al. (1976) noted that the puzzle was designed to be both entertaining and challenging. In this sense, the puzzle itself, the collection of specially designed wooden blocks, performs part of the recruitment function, which, as noted previously, is a function of scaffolding. More important, the puzzle consists of a number of characteristics that extend and limit the range of possible actions and errors. For example, the feature that each peg can fit into each hole increases the range of possible actions and therefore the possibility of error and the complexity of the task. A child can insert the peg of a block intended for Layer 3 into the hole of a block on Level 1, which would prohibit the correct construction of the pyramid because Level 2 is omitted. In contrast, the matched elevation at the top and depression at the bottom of the blocks reduces the degrees of freedom and assists the child in the construction process because it suggests a particular way of orienting the blocks. The blocks have certain affordances and constraints (Norman, 1988; Wertsch, 1998, p. 29) that mediate the construction of the pyramid. Therefore, it is the tutor, the blocks, and the child that come together in constructing the pyramid.

SCAFFOLDING AS MEDIATED ACTION

This emphasis on activity and on enabling performance and learning through performance is what distinguishes scaffolding from other forms of educational support (Guzdial, 1994). This is what Stone (1998a) referred to when he stated that "the scaffolding metaphor also creates instant links to a theoretical and empirical tradition within the field of developmental psychology that brings with it, for better or worse, a good deal of theoretical baggage" (p. 344). Most directly, scaffolding is associated with Vygotsky and his ideas concerning the zone of proximal development (ZPD; Bruner, 1985; Cazden, 1979). Current approaches consider this theoretical framework to also include the work of Vygotsky's students and colleagues such as Luria and Leontiev and the contemporary interpretations and extensions of their views (Cole, 1996, p. 104). This can be generally referred to as sociocultural perspectives that treat activity as the focus of analysis (e.g., cultural psychology; Cole, 1996; activity theory; Engeström, Miettinen, & Punamäki, 1999; distributed cognition; Salomon, 1993; and mediated action; Wertsch, 1998).

Two ideas from these traditions are especially pertinent to this discussion. The first idea is that learning precedes or drives development (e.g., Cazden, 1979). Unlike models that stipulate the need to achieve a level of mental maturity as a prerequisite to contending well with particular tasks, in this framework, the ability to contend with tasks develops through assisted performance. This idea is tied to the concept of the ZPD. The actual development is the range of activity that can be accomplished independently. The ZPD is the range of activity that can be accomplished under guidance but not independently. Children's assisted performance of tasks in their ZPD creates the circumstances in which these interactions are eventually appropriated, thus extending the child's actual developmental level. In this sense, the learning, the process of assisted performance, drives development by changing or shifting the "zones" of actual and proximal development. Helping learners perform in their ZPD and extending their actual developmental level is the essence of scaffolding (Cazden, 1979; Cazden, 2001, p. 71).

The second idea concerning sociocultural perspectives that is pertinent to this discussion is that all action is mediated through the irreducible tension between agents and mediational means (Wertsch, 1998, p. 30). *Mediational means,* also referred to as cultural tools, are any and all tangible and intangible objects such as visual representations, sign systems, or technical tools that are involved in human action. Thus, a pole used in the track-and-field event of pole vaulting (Wertsch, 1998, p. 27), the initiation-response-evaluation discourse pattern typically found in classrooms (Mehan, 1979; Polman & Pea, 2001), and Euler's formula (Wertsch & Rupert, 1993) are each examples of cultural tools.

Wertsch (1998) offered a pithy example for understanding this second idea. Consider being asked to multiply 343 by 822. Who can be said to be doing the multiplying? If we use the typical representation of the vertical array most people can arrive at the solution fairly easily. However, if we were asked to multiply these two numbers without the use of the vertical array representation, we would be stumped. In this sense, the vertical array representation, the cultural tool, can be said to be doing part of the act of the multiplication (Wertsch, 1998, p. 28). However, it is impossible to separate the person multiplying from the representation used or to qualify the distribution of the task between the two. There is an irreducible tension between the agent and the cultural tool (Wertsch, 1998, p. 29).

As I noted in the introduction, in this article, development or gaining independent proficiency in a task is viewed as appropriating disciplinary ways of knowing, doing, and talking. From a sociocultural perspective, this means that learners become facile in the use of the relevant cultural tools in the discipline. Pea (1992) further noted that tool use is not inherent to the tool; rather, we need to learn the culturally appropriate ways of using cultural tools (see also Cole, 1996; Wertsch, 1991). For example, Wood et al. (1976) noted that the children who participated in their study were often eager to construct other nonpyramid structures using the set of blocks. An important part of the tutor's facilitation involved introducing and promoting the pyramid-construction way of using the blocks as well as helping the children adhere to and not stray from that way of doing.

Cultural tools and mediational means are often used interchangeably. In discussing scaffolding, it might prove useful to consider cultural tools and scaffolding as two subordinates of the more general mediational means. *Cultural tools* refer to the mediational means that have an extended past rooted in the history of the sociocultural setting in which they were created (not necessarily with a particular purpose in mind; Wertsch, 1998) and have a potentially long future. They are associated with a single or set of culturally meaningful tasks and practices. Scaffolding refers to the mediational means that have been created for the explicit purpose of helping learners develop proficiency with some cultural tools. Scaffolding are mediational means that we do not expect to persist in the future.

I reconsider the multiplication example. The vertical array representation is a cultural tool. Initially, learners may not have great facility in using this cultural tool. They may not consistently shift each subsequent row of the derived solution one digit to the left and may not recognize the mathematical significance of keeping the digit columns well aligned. The goal of any scaffolding educators employ or attempt to design, is to help learners reach a point where they spontaneously write numbers in a vertical array representation when asked to multiply and consistently and effectively shift subsequent rows one digit to the left, keeping digit columns aligned. We might devise a special notational template with clearly marked slots in which learners fill in the digits of the numbers they produce at each step of the solution. This template is a scaffold that helps the learner use the cultural tool of the vertical array in the expert or socially valued way. We expect the template to be a part of the multiplication act for a limited duration, but we expect the vertical array to be a part of the multiplication act for the foreseeable future. Thus, even when learners or children extend their actual zone of development, they never really act independently; their activity is always mediated by cultural tools. Although the cultural tools are used indefinitely, they are not fixed entities. Cultural tools are malleable and subject to change within each use or over time (Pea, 1992; Wertsch, 1998).

HOW AND WHY SCAFFOLDING SHOULD BE DISTRIBUTED

Added Value of the "Distributed" Label

I have argued that scaffolding can be embedded in artifacts and that scaffolding for a particular task can be distributed across agents and artifacts. I further noted that this is consistent with the theoretical framework, sociocultural perspectives focused on activity, in which the scaffolding metaphor is rooted. If the notion of distributed scaffolding is inherent to the scaffolding metaphor, what do we stand to gain from appending distributed to scaffolding and from incorporating a new label? As Stone (1998a) suggested, the use of particular labels brings with it "theoretical baggage." I have alluded previously that the label scaffolding can tend to conjure images of single adult human agents (cf. Palincsar, 1998).

In invoking the term distributed scaffolding, I hope that the theoretical baggage that is brought to bear encourages educators to consider three main issues: (a) developing deep conceptual understanding and sophisticated ways of producing and defending knowledge claims is a gradual process that requires innovative and complex support over extended periods of time (Brown & Campione, 1994; Krajcik et al., 1998, 2000; Linn, Bell, & Hsi, 1998; White, 1993); (b) there are multiple ZPDs in the classroom (Brown et al., 1993; Palincsar, 1998), that is, different learners are familiar with different cultural tools, and different learners have different levels of facility with different cultural tools; and (c) a variety of material and social means can provide different affordances and constraints and can work in concert over time in helping students gain facility with the relevant cultural tools. In what follows, I explain how these ideas give rise to different patterns of distributed scaffolding.

Three Patterns of Distributed Scaffolding

The basic idea behind distributed scaffolding is that developing disciplinary ways of knowing, doing, and communicating entails a large assortment of learning or support needs. What is considered the task in these contexts is much more complex and extends over longer periods of time than the tasks depicted in the initial or classical examples of scaffolding. Therefore, profitable conceptions of scaffolding need to change accordingly.

Consider the main demands of the task of constructing a puzzle—one of the classical scaffolding examples—identifying pieces that make up the border, assembling the border, and identifying the desired location of a piece by mapping its location in a model picture to its location in the emerging puzzle. Contrast this with the domain of inquiry-based science. Here, the task involves articulating a researchable question; designing and executing an investigation; and constructing, communicating, and defending explanations according to established norms and criteria. Each one of these components can be a considered a complex task in and of itself that incorporates the use of discipline-specific cultural tools but is outside the immediate grasp of students.

Designing an investigation, for instance, involves identifying variables that are pertinent and promise to produce relevant information. It also includes devising ways to control and manipulate these variables to be able to reach reliable conclusions regarding causal relations such as by using the cultural tool of vary-one-variable-at-a-time. It is hard to imagine how a single instructional support or agent can structure, assist, and assume partial responsibility for the many aspects involved in designing an investigation while also doing the same for the many aspects involved in executing an investigation or constructing an explanation or any of the other components of inquiry. This is particularly difficult in classroom contexts in which one teacher is working with several individuals or work groups reflecting a range of ZPDs (Puntambekar & Hubscher, in press).

It is not just the magnitude or complexity of the support needs but the diversity of support needs that motivates the appeal to multiple means and agents of scaffolding. Studies examining the practices of novices in attempting to conduct scientific inquiry reveal a rich set of support needs that learners require in making the transition from everyday to scientific practice (Hawkins & Pea, 1987). Students need help in developing scientific argumentation and communication skills (Jimenez-Aleixandre, Rodriguez, & Duschl, 2000; Lemke, 1990) and in viewing their actions in relation to theoretical and epistemological foundations (Carey, Evans, Honda, Jay, & Unger, 1989; Hogan, 1999; Sandoval, 2003; Sandoval & Morrison, 2003). Some specific areas of difficulty include framing questions that are amenable to experimentation and meaningful conclusions (Krajcik et al., 1998), making normative interpretations of data (Roth, 1995; Snir & Smith, 1995; White, 1993), reflecting on the pertinence and evidentiary force of data (Davis, 2003; Loh et al., 2001; Tabak, Sandoval, Smith, Steinmuller, & Reiser, 1998), as well as directly supporting claims with evidence (Bell & Linn, 2000; Germann & Aram, 1996; Sandoval, 2003). Each one of these needs can be thought of as a qualitatively different task that is outside the current reach of the students, thus requiring assisted performance. Each invites different forms of support.

Software scaffolds, tangible objects, teacher coaching, and individual or group configurations each have different affordances. These different materials, activity structures, and agents offer unique contributions for supporting different types of reasoning, actions, or tasks. Software scaffolds may be more useful when the need for support is ongoing such as for employing a particular expert process in making step-by-step inquiry decisions (Guzdial, 1993; Hmelo & Guzdial, 1996). Yet, teacher or peer support can be more effective when successive, incremental turns of immediate feedback, repair, and elaboration are required (Hogan, Nastasi, & Pressley, 1999).

Distributed scaffolding, marshaling a collection of agents, artifacts, and participant structures to support disciplinary learning, is one way to capitalize on these affordances and constraints. Yet, as noted briefly earlier, distributed scaffolding can be envisaged in different ways. One way is what I refer to as differentiated scaffolds in which different mediational means are intended to support a different aspect of performance or learning need. Another way is to think of distributed scaffolding as opening up multiple opportunities in which students can achieve the same performance with assistance, what has been referred to as redundant scaffolds (Puntambekar & Kolodner, 1998). I also propose a third pattern, synergistic scaffolds in which different supports interact with each other in providing the scaffolding.

As a first step toward the formalization of distributed scaffolding and the development of principles for its design, I summarize in this section the pedagogical and design rationale underlying these three patterns of distributed scaffolding. In the remaining sections, I extend the discussion of the third pattern, synergistic scaffolds, which is introduced in this article. These three patterns are not mutually exclusive, and a single curriculum can reflect all three patterns.

Differentiated scaffolds. The differentiated scaffolds pattern is the basic pattern motivating distributed scaffolding. It responds to the fact that current educational goals place students as active agents in complex tasks, which raises a large set of support needs that a single method of support cannot provide. The goal in implementing this pattern is to identify the range of support needs and to identify the type of agent or material that best supports each need. Thus, each need is addressed by its own scaffold, as depicted in Figure 1.

One example of how different means are better suited to support different needs can be found in the BGuILE project (Reiser et al., 2001) in which students deepen their understanding of evolution by investigating simulated episodes of natural selection in the wild. The simulation environment, The Galápagos Finches (Tabak, 1999) and an accompanying tool, ExplanationConstructor (Sandoval, 2003) in which students can write out their free-text explanations, included a set of prompts for the components that make up a natural selection explanation such as identifying an environmental pressure and an advantageous trait. These prompts were useful in helping students construct explanations that contained the necessary parts that make up a natural selection explanation (Sandoval, 2003). They provided a constant yet fairly unobtrusive reminder concerning profitable targets of investigation. In contrast, support provided by the teacher during a whole-class discussion was more directed and intrusive. During a whole-class discussion, students presented their final explanations. As the students presented their accounts, the teacher interjected with a series of questions and prompts, having the students pause their account and reiterate in response to her prompting. This form of support helped students move from short-hand, everyday-type constructions to more

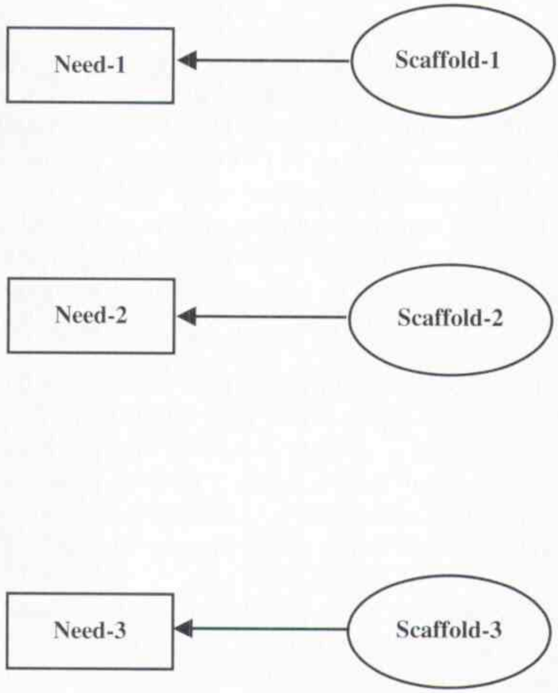

FIGURE 1 Differentiated scaffolds model.

detailed and explicitly causal constructions (Tabak & Reiser, 1999). The constant unobtrusive scaffolds were helpful in formulating the students' understanding of the phenomenon and an initial formal explanation. The directed and dialogic scaffolds were helpful in refining the formal explanations.

Another example of differentiated scaffolds is provided by the Learning by Design (LBD) project (Kolodner et al., 2003) in which students learn scientific principles by creating designs that respond to a particular design challenge. As students work on their designs, they keep diaries in which they document their design process. These diaries contain prompts that encourage students to describe the considerations they raised in deciding between alternative design options. Puntambekar and Kolodner (1998, in press) have found that the solitary process of responding to prompts made students stop and take stock of the considerations they had raised, yet it was not as effective in making students justify their designs in terms of scientific principles. However, a different activity, referred to as a *pin-up session* in which students display and discuss their designs with other groups, was effective in eliciting scientific justifications. These pin-up sessions involve interacting with an audience, which helps students develop criteria for what constitutes a good and convincing justification.

Therefore, by bringing together multiple sources of scaffolding, educators are able to respond to the diverse support needs that arise in classrooms that aim to cultivate sophisticated reasoning and disciplinary practices (Krajcik et al., 2000). The pattern of differentiated scaffolds encourages us to consider the range of learning needs that our students might express and the unique strengths of different materials and agents. The design process involves aligning the needs with the best form of support available.

Redundant scaffolds. Even a collection of supports addressing different aspects of learning may not be sufficient to fully address the needs of all students. Different students possess different competencies and might require different levels of support with respect to particular learning needs. Including multiple supports that target the same need (Rogoff, 1999) can cater to the multiple ZPDs that are present in a classroom (Brown et al., 1993; Palincsar, 1998). This is achieved through the redundant scaffolds pattern.

The redundant scaffolds pattern recognizes that some students will miss opportunities to benefit from a particular scaffold and that some students will require more support than others. The goal in redundant scaffolds is to provide multiple scaffolds for the same need. This can be achieved by providing different supports through different modalities that appear at one point in time or sequenced at different points in time in a curriculum or unit. This enables students who were not able to benefit from one scaffold to utilize another scaffold or students who require greater assistance to receive more help. Unlike the differentiated model, in this model, the same need can be addressed by multiple scaffolds as show in Figure 2.

Puntambekar and Kolodner (1998, in press) have maintained that redundant scaffolds maximize the chances that students will actually benefit from a scaffold. This is important because any scaffolding interaction can include improp-

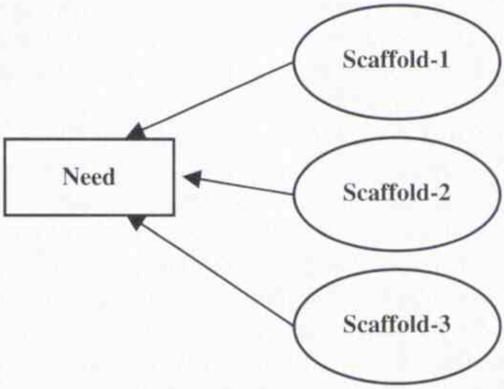

FIGURE 2 Redundant scaffolds model.

erly calibrated scaffolds or possible missed opportunities for providing necessary support (Greenfield, 1984; Wood et al., 1976). It is even more significant in classroom contexts in which such "misses" cannot be immediately diagnosed and repaired as in one-on-one tutoring situations (see also Puntambekar & Hubscher, in press). If students do not attend to or do not understand a particular scaffold, they have an additional opportunity to benefit from the same class or category of supports. For example, in the LBD curriculum described earlier (Kolodner et al., 2003; Puntambekar & Kolodner, 1998), there are two separate opportunities and means for prompting students to describe the considerations they raised in deciding between alternative design options. One means is through the prompts in the design diaries described in the examples pertaining to differentiated scaffolds. The second means is prompting from the teacher during subsequent whole-class discussions in which he or she also presses students to describe what alternatives they raised and how they decided among these alternatives. Students who did not understand the intent of the prompt or were too immersed in the course of the design to attend to the prompt have an additional opportunity to engage in this reflective process.

The design pattern of redundant scaffolds drives design efforts toward attending to the multiple ZPDs that exist in classroom contexts. Of course, matching the affordances of particular materials and instructional strategies to particular needs is still a goal. However, in the case of redundant scaffolds, more attention is directed toward devising multiple ways to provide the same type of support.

Synergistic scaffolds. I posit that there is another important characteristic in addition to redundancy associated with the inclusion of multiple supports targeting the same need. This characteristic is synergy. Redundant scaffolds open up multiple opportunities in which students can perform the same task or achieve the same goal under guidance. As the previous example demonstrates, the diary prompts guided reflection about alternatives at one point in time, and the teacher prompts guided reflection about alternatives at a second point in time. In contrast, synergistic scaffolds are different supports that augment each other; they interact and work in concert to guide a single performance of a task or goal.

The rationale underlying this pattern is that some of the skills and practices that we are trying to foster integrate such a mélange of knowledge, skills, and values that few if any individual mediums or agents exist that would be able to support the development of these practices. It takes the concerted efforts of multiple scaffolds, some introducing a set of possible tools and actions, some communicating the utility of these actions, and others demonstrating how these actions can be coordinated to produce valued activity. Performance involves an integration of all of these aspects; therefore, learning through performance is facilitated by scaffolds or a system of scaffolds that simultaneously embody this full gamut of supports. The intentional and consistent design of coconstituted supports is essential to effectively implementing this pattern. In synergistic scaffolds, scaffolds are not only directed toward the same need, they are enmeshed, intertwined, and complete each other as shown in Figure 3.

For example, software scaffolds and teacher scaffolds can come together and interact to support the act of making systematic comparisons that are valued in the discipline (Tabak & Reiser, 1997). The software can present students with a set of options that represent the type of comparisons that are valued in the discipline, and the process of setting up a comparison can be structured so that students cannot vary more than one variable at a time. The teacher can explicate the rationale that underlies these practices and model their use. However, it can be easier for students to apply the lessons from this modeling if the teacher models this thinking while she or he uses the software that the students are using.

Thus, profitable comparisons are simultaneously supported by the software and the teacher as the teacher interacts with the software, making appropriate menu selections and voicing her rationale for taking these actions. Modeling these strategies in the abstract, in the absence of the software tools used to enact these strategies, is awkward. The software scaffolds alone cannot fully communicate the dynamic, moment-by-moment reasoning that guides the choice of actions available in the software. Thus, student performance is facilitated through the combined contribution of the teacher and the software working as a system. This idea is elaborated with excerpts of classroom interactions in the next section.

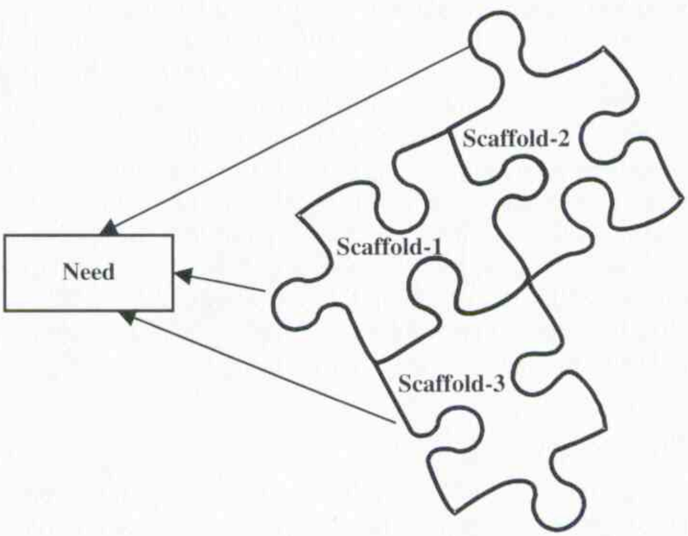

FIGURE 3 Synergistic scaffolds model.

AN EXTENDED LOOK AT SYNERGISTIC SCAFFOLDS

Synergistic scaffolds can provide a response to the confluence of instructional challenges posed by the complexity of the learning goals, the diversity of learning needs, and the onus of fostering culturally appropriate use of cultural tools. As I have noted, viewing learning from a sociocultural perspective means that educators are trying to introduce students to the cultural tools that are prevalent in the discipline and to help them develop facility with their use. The process of scaffolding is not only intended to promote competence in the use of these cultural tools but to advance the culturally appropriate use of the tools. One source of scaffolding might introduce particular cultural tools and structure students' use of these tools. Other sources of scaffolding might communicate what norms, actions, and practices are privileged in the discipline. The synergy between these scaffolds can foster culturally appropriate use of the tools.

For example, software scaffolds that structure and guide students' actions (Guzdial, 1994) can present varying-one-variable-at-a-time as a cultural tool available for student use in the process of their investigation. Students are invited to exploit these scaffolds, and they are also free to decline, overlook, or discount them. Even if supports are utilized, they may not be sufficient because students may not interpret them as intended by designers and educators. They may not interpret them according to cultural or disciplinary conventions.

For example, scaffolds that constrain students to vary-one-variable-at-a-time do not guarantee that students understand the utility of this method or that they are able to integrate it with the explanatory demands of the discipline. Yet, if these types of scaffolds are augmented with additional supports, particularly the flexible, dynamic, or just-in-time support of the teacher so that the teacher and software work in concert, it increases the likelihood that these supports will be understood and effectively used. Once the tacit disciplinary knowledge that underlies the coordination of a sequence of actions using the tool is modeled with the use of the software, students may be able to take advantage of the software supports without additional guidance. Therefore, if students can use these tools effectively, one can say that they have achieved independent performance because one expects some tools to always be part of their actions. Tools that have a high fidelity (Collins, 1996) to the tools used by experts or professionals are likely to be part of ongoing practice and will not be eliminated as students gain proficiency.

Synergistic Scaffolds: An Illustration

These ideas are illustrated with the following sequence of three classroom vignettes. These vignettes are included here as illustrative examples. Further illustration of the synergy between software and teacher scaffolds can be found in the larger study from which these vignettes are drawn (Tabak, 1999).

The episodes demonstrate the progressive refinement of a group of students' use of a cultural tool, structure-function reasoning, that is part of a biologist's toolkit.[1] Considering structure-function relations is a central component of biological reasoning (Biological Sciences Curriculum Study, 1993). Yet students may not be aware of this cultural tool or know how to employ it. Students often need guidance in determining which variables are most pertinent in a particular discipline or investigation context (Lewis, Stern, & Linn, 1993) and may find it difficult to orchestrate a sequence of strategies to achieve the task goal (Brown & Palincsar, 1989). Therefore, instances in which students independently and systematically employ structure-function reasoning to guide their inquiry decisions represent profitable disciplinary practices and a nontrivial achievement.

All three vignettes include the same group of three high school students, Tanya, Cathy, and BK. They are students in a regular level introductory biology class in a public high school in a large city in the Midwest. The students are working on an investigation that is part of a 5-week curricular unit on evolution. This unit is part of the BGuILE project (Reiser et al., 2001) described earlier. The unit includes traditional laboratories and first-hand investigations. The investigations typically span four to eight 45-min class sessions and interleave investigation work with whole-class discussions about the investigations.

In this example, the students are trying to explain differential survival of a population of finches (small birds) on a Galápagos island during a period of extreme and unusual mortality. The students are using a software environment, The Galápagos Finches, to investigate this problem (Tabak, Reiser, Sandoval, Leone, & Steinmuller, 2001; Tabak, 1999). The software includes a limited but still fairly complex scope of the data available to researchers on the island. The software scaffolds are designed using the approach of discipline-specific strategic support (Tabak, 1999), which makes tacit conventions of disciplinary investigation practices—the relevant cultural tools—overt, and structures students' data analysis and

[1]My use of structure-function reasoning in this context is not technically accurate. The episode that the students are investigating involves a case in which the depth of a bird's beak enables it to crack larger seeds. The structure of the beak influences its function, its "seed cracking" efficacy. This would be a more technically accurate use of the term structure-function reasoning. However, in the vignettes that I present, I use "the finches' behavior" interchangeably with function. This is where I deviate from technical accuracy. I do this because it is easier for the students to think in these terms because they are basing their judgments on descriptions, field notes, of the finches as they forage. Structure-function reasoning refers to reasoning at the same biological level. To make the natural selection argument concerning selective advantage, it is necessary to make judgments at one level, the structure and function of the beak, and then make judgments at another level, the organism level, to consider the selective advantage. However, stating the argument with such technical precision adds complexity that I thought was beyond what the students could manage at this point. Therefore, I use the short-hand of speaking of physical characteristics and behavior in the context of structure-function reasoning. This short-hand was examined by a number of consulting biologists and by biologists who were not involved in the project, and they did not find this short-hand prohibitive.

synthesis according to these conventions. In this case, students employ a set of menus to construct questions that reflect the conceptual questions that evolutionary biologists might raise.

One question that is relevant to studying natural selection in the wild is whether there are changes in the variation of structural traits across time. Figure 4 shows how such a question can be constructed by selecting a comparison type (e.g., "Are there changes between time periods in the …?") and then selecting a variable type to compare (e.g., "… variation of structural traits?"). After selecting the comparison type and variable, a dialogue box appears, also shown in Figure 4, in which students can select the specific trait they want to examine and the time periods across which this comparison should be made. This acts as a query to the database and brings up a new window with the resulting data (see Figure 5 for examples of the types of available data). Data are available for a prestress baseline period, for the period of environmental stress, and for a poststress period. Data sources include environmental factors (e.g., rainfall), plant life (e.g., number and characteristics of various seeds), as well as the physical characteristics (e.g., wing length, beak length) and behavioral characteristics (e.g., foraging behavior) of the finches. The behavioral data appear in field notes, which are textual descriptions of the finches' behavior. They are designed to reflect the field notes that scientists might collect in the field, although they are not veridical copies of the observation sheets used by scientists in the field. These field notes figure prominently in the example episodes

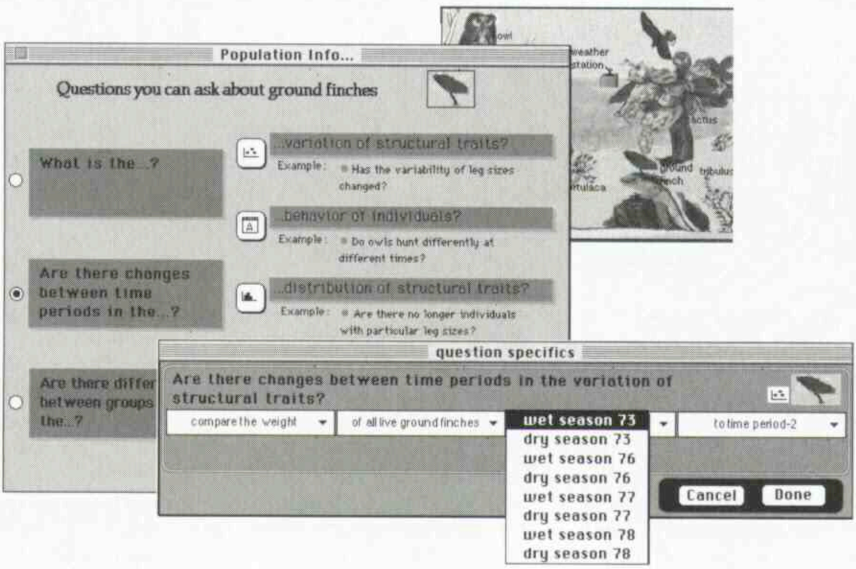

FIGURE 4 Cultural tools—longitudinal comparisons in the variation of structural traits—reified as menu selections.

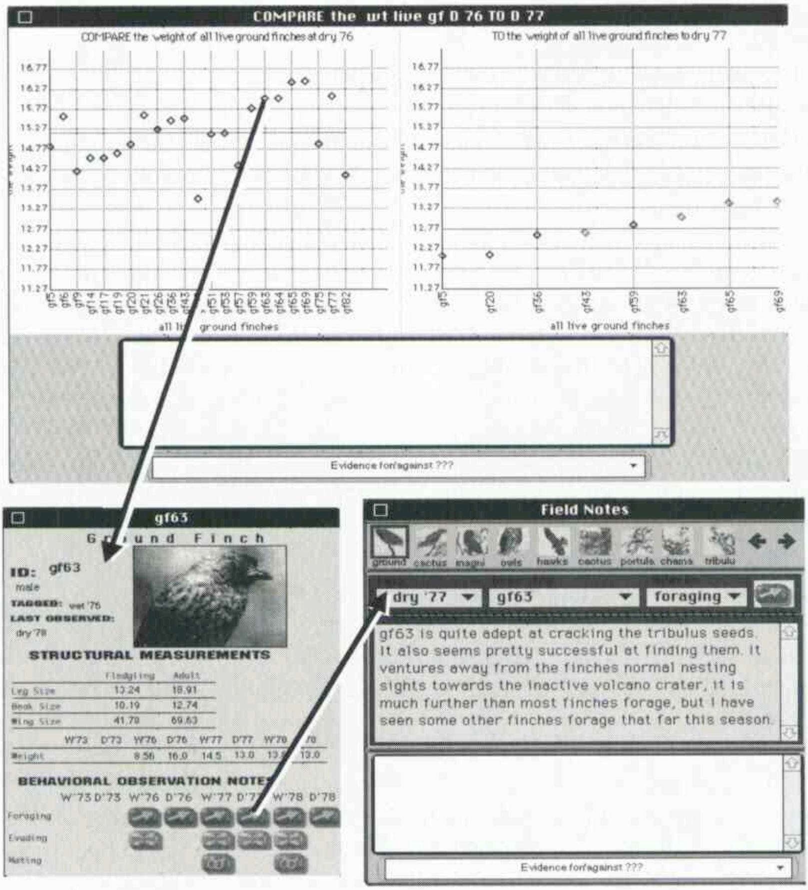

FIGURE 5 Multiple data sources linking physical characteristics and behavioral characteristics.

following. Data on the finches are available at both the individual and aggregate levels.

The three episodes are depicted in chronological order. The first two episodes occur on the same day, followed a few days later by the third episode. The first episode shows Tanya, Cathy, and BKs naïve use of structure-function reasoning. The third episode shows BK employing structure-function reasoning in a culturally appropriate way. In the intervening, second episode, the teacher and the software scaffolds work in concert in helping the students take up the culturally appropriate use of structure-function reasoning. Therefore, there is some suggestion that this intervening episode played a role in the development of the mastery of the cultural tool of structure-function reasoning that is seen between the first and third episodes.

This sequence of episodes illustrates how the software scaffolds introduce and provide access to cultural tools. The synergy between the software scaffolds and the teacher's scaffolding makes the culturally appropriate use of these tools visible to the students. Thus, students take up these cultural tools and employ them in culturally appropriate ways.

Episode 1. In the first episode, only the students are working with the software. The episode takes place during the second class session devoted to investigation. During the first investigation session, they had examined some field notes and noted that different finches ate different food (e.g., spiders and different seeds). In the current class session, prior to the segment quoted following, they had examined a graph depicting the leg length of all the live ground finches during a period of stress. From this graph, they brought up "individual profiles"—a screen depicting all the known information about an individual finch. They accessed this individual data by clicking on the individual data points in the graph. In these individual profiles, they can click on links to fields notes depicting the behavior of the individual finch. Figure 5 shows these different data sources and the links between them.

The segment opens with the students attempting to explain to themselves why some of the finches survive. They recall their findings from the previous day concerning foraging and try to relate it to their current findings about size. The students exhibit an initial propensity for using the cultural tool of structure-function reasoning because they decide to turn to examining physical characteristics (structure) after noting differential patterns of behavior (function). However, they do not demonstrate great facility with this cultural tool. They are not very directed in their exploration of the physical data and do not formulate conjectures about specific physical characteristics such as wing length or beak length that might be related to the behavior they observe.

1. Tanya: But why would some of them survive, because they are not all eating the same thing? Right? Remember some are eating spiders, some are eating seeds, some are eating vegetables
2. Cathy: Well let's write down what these that are alive and everything, like all of them
3. Tanya: We're at 36 [each individual finch is identified by a tag number, they are observing a field note—see Figure 5], do you want to write that down, his leg length, his beak size and his wing length and compare to some dead ones?

The software was designed to encourage students to reason about structure and function by making the movement between these two types of data salient and smooth (through the questions they can construct as shown in Figure 4 and in the links between data sources as shown Figure 5). Although the students do move sequentially between data concerning behavior and data concerning physical characteristics, they do not do so in a way that reflects expert practice. Expert practice would tend to examine a particular physical characteristic that could be related to the interesting patterns in eating behaviors that are observed. For example, Tanya and Cathy might raise conjectures about whether beaks or legs were instrumental in hunting spiders and what qualities of either beaks or legs would make one a better hunter. It is not clear whether the students were predisposed to think in terms of structure and function or whether the software prompts them to do so, but either way, the interaction between the students and the software lends their performance the semblance of structure-function reasoning. However, they are not using the cultural tool of structure-function reasoning in disciplinarily normative ways.

Episode 2. In the second episode, the teacher joins the group, and the teacher and students work together as a group with the software (Tabak & Baumgartner, in press). In this second episode, one sees how the teacher works in concert with the software to scaffold students into normative structure-function reasoning. The teacher models the more facile use of the structure-function reasoning cultural tool by voicing how she raises conjectures concerning particular physical characteristics after noting an interesting behavior.

1. Ms. Patrick: But that guy goes farther than most other finches forage, oh, that tells me, maybe his transportation is better, since these are ground finches, they don't fly, so it might have something to do with their legs
2. Tanya: We did leg length
3. Ms. Patrick: Is there a significant difference between dead ones and live ones in their leg length?

In line 1, Ms. Patrick, the teacher, demonstrates how a description of behavior can drive conjectures concerning function: "oh, that tells me, maybe his transportation is better." The example goes on to show that she demonstrates how it is possible to analyze and consider which physical characteristic might enable that function: "since these are ground finches, they don't fly, so it might have something to do with their legs." Here one sees that Ms. Patrick models a more refined deployment of the structure-function cultural tool. Unlike the students' use of the tool in the first episode in which there were no conjectures linking a specific behavior with a specific trait, here Ms. Patrick is specifically linking "the ability to go far" with "something to do with their legs." The teacher demonstrates how the movement between behavioral and structural data, salient in the software representations, can be used to reason about structure and function in expert ways, and she does this while she herself manipulates the software representations.

Episode 3. In the third episode, which occurs later in the unit, one sees how the students have taken up this more sophisticated and culturally appropriate use of the tool and perform this practice through the mediation of the software. Again, the teacher and students are working with the software together, but it is one of the students, BK, that exhibits the expert-like form of structure-function reasoning. The segment opens with the group reading a field note. The field note describes how a finch walked up to a patch of seeds where other birds were foraging, but when it got to the patch, all the seeds were already cracked open. The students and the teacher are discussing what the field note depicts.

1. BK: We got two things we can tell from this [the field note] this is gf20 right? [referring to the individual finch's tag number] He saw other finches eating it, but by the time he got there, they had already finished eating.
2. Ms. Patrick: Cracking open and eating tribulus [reads from field note]
3. BK: So he, was either too slow or
4. Ms. Patrick: Ooh or his beak wasn't strong enough
5. BK: No, it's not his beak, by the time he got the shells was already broken, so he was too slow
6. Ms. Patrick: Maybe
7. BK: Maybe it's his leg size

This episode is quite similar to the previous episode. However, the type of conjectures raised by the teacher in the previous example are now raised by a student. The student, BK (line 1), notes that the finch did not reach the food on time and suggests that the finch is slow (line 3). The teacher offers an alternative conjecture that the issue is strength governed by beak size (line 4). BK discounts this alternative by noting that the shells were already broken by the time the finch got to the area (so beak strength could not be a factor), and again he raises the idea of slowness (line 5). The teacher concedes that this is a possibility (line 6), and in line 7, BK fully exhibits structure-function reasoning when he relates the "slowness" to a hypothesized characteristic "leg size." At this point, BK is showing some mastery over the cultural tool of structure-function reasoning.

This sequence of three episodes illustrates how two elements of the distributed scaffolding system, the software scaffolds and the teacher scaffolds, work in concert to enable students to utilize structure-function reasoning in the process of an investigation. The software scaffolds pushed students to take these types of actions by making structure and function visible and salient objects and by enabling smooth transitions between these data types. However, the software scaffolds alone may not have been sufficient to promote the culturally appropriate or expert use of these tools, as is suggested by the first episode in which the students' independent performance did not reflect expert practice. The teacher's modeling using the software in the second episode suggested the importance and desirability of these actions and made the logic that motivates such moves visible, paving the way for the subsequent expert practice on the part of the students that was displayed in the last episode.

Function of Synergistic Scaffolds

Sherin et al. (this issue) noted the importance of considering scaffolding in terms of its functions. The main function of synergistic scaffolds, as illustrated previously, is to cultivate culturally appropriate tool use by marking critical features and privileged meanings and practices. Considering scaffolding in terms of mediated action has placed a higher premium on the role of artifacts in supporting learners. In some cases, these tools will be scaffolds designed for the purposes of learning such as the software environment in the preceding example. In other cases, these tools will be the cultural tools of the discipline such as structure-function reasoning, which is a tacit tool that was made overt and embedded in the software described previously.

As noted earlier, mediational means do not shape actions in a deterministic way (Wertsch, 1998). This is further qualified by Pea (1992) who pointed out that the affordances and constraints of a particular tool still leave enough degrees of freedom such that an "outsider" may not use the tool in the same way as "insiders." The underdetermined nature of artifacts and its implications for synergistic scaffolds was even evident in the example of the Wood et al. (1976) study discussed previously. Wood et al. had pointed out that the children who participated in the study had their own notions regarding how to use and assemble the puzzle blocks and for what purposes. An important component of the tutor's role in the study was to "bring the children in" to the goals and appropriate procedures of the pyramid-construction task.

Similarly, in the illustration before, Ms. Patrick in her interactions with the software brought the students into the practice of biology. The synergy between the software scaffolds and the teacher scaffolds is expressed through a bidirectional relation.[2] The structure of the software and the software representations communicate to the teacher the features that are privileged in the discipline and that should be marked in her interactions with students.[3] In turn, the fact that the teacher's modeling was rooted in the language of, objects of, and direct manipulation of the software scaffolds imbues them with meaning. What might be initially perceived

[2]This is similar to what Michaels (2002) referred to as the task/talk amalgam.

by the students as a collection of buttons to be clicked and menu options to be selected become conceptually meaningful representations. This enables students to heed the scientific and biological tenets and conduct themselves in disciplinary ways. It is this coming together and coconstitution of supports that lends them pedagogical power (Lehrer & Schauble, 2000).

Productive synergy between supports is not confined to a teacher utilizing software tools. Synergy can occur between different material supports and over a sequence of interactions between different activities. Materials that share semiotic features across activities can focus students on the important concepts in the domain. They can help students distinguish between practices that are central to the discipline and actions that are incidental to completing a particular activity. This interaction can be strengthened if the teacher explicitly directs students to attend to these similarities and helps them differentiate surface from deep features. Such a juxtapositioning of texts (or artifacts and events) is referred to as "intertextuality" (Gee & Green, 1998). From a Vygotskian perspective, learning occurs both in the moment and over time in which every event has an implicated future and an intertextual past (Putney, Green, Dixon, Durán, & Yeager, 2000). Students and teachers negotiate what is meaningful and significant by relating to ideas from previous events and by projecting to future events. What members bring from prior events signifies what cultural knowledge is consequential for the participants (Gee & Green, 1998; Putney et al., 2000).

If one treats intertextuality from a design rather than an analytic perspective, then there are two implications for achieving the function of synergy in distributed scaffolding. First, there should be a thematic continuity between materials and instruction that reflect the critical features of activity in the discipline. Second, the juxtapositioning of these similar tasks, materials, and discussions should be explicitly encouraged.

In the study from which the preceding example episodes were taken (Tabak, 1999), I observed this same student group juxtapose a prior investigation with this investigation to decide which variables to study. The instructional materials used in each of the two investigations shared the same conceptual entities and representations (e.g., "compare variation in structural traits across time"), even though the first was a paper-based activity, and the second was a software-based activity, and each focused on different evolutionary phenomena. In addition, during a

[3]Anecdotally, the teacher in the study from which the classroom episodes were taken noted that she had always emphasized comparison (a feature that is marked in the software) but not relations (another feature that is marked in the software). She stated that using the software reminded her of the significance of forming relations and that she now tries to emphasize that in her instruction, even outside the scope of curricular units that utilize the software. Palincsar and Magnusson (2001) described similar reification of curricular designs in the teacher's discourse. These ideas are consistent with the way Ball and Cohen (1996) characterized learning in classrooms as the interaction between teachers, students, and materials.

whole-class discussion that segued between the two investigation activities, the teacher encouraged the students to draw on their experiences and findings in the first investigation to raise conjectures and plans for the second investigation. This combination of similarity and explicit directives to compare may have played a role in sparking the spontaneous analogy I observed in the student-group's independent work.

It is not surprising that different resources interact and that the combined contribution of multiple supports is greater than the contribution of fewer supports. However, it is not necessarily the case that supports will interact or that they will interact in profitable ways. For example, in a study examining the patterns of discussion in a class combining computer-mediated and face-to-face discussions, Lee and Songer (2001) found that there were a number of instances in which the teacher had missed opportunities for conceptual scaffolding. Lee and Songer speculated that the teacher missed these opportunities because she perceived the curriculum to consist of two separate and distinct units, each involving a different set of materials and addressing disparate learning goals. She may have considered a novel computer-based curriculum to be appropriate for fostering inquiry skills and an existing paper-based curriculum to be appropriate for conceptual issues. Thus, she was less likely to attend to conceptual issues when supporting students' performance in the computer-based investigations.

This suggests that for productive synergy to occur, like the dynamics in the classroom interactions quoted in the preceding episodes, different materials need to share semiotic features, and these features need to be consistent not only with the designers' but with the teacher's conception of the task, goals, and discipline. It is often dangerously tempting to assume that if carefully designed materials are introduced into the classroom, then they will necessarily shape the intellectual climate in the class (see also Wertsch, 1998). In fact, even if there is coherence between the features of the materials and the teacher's conceptions, there is no guarantee that productive synergy will occur. Therefore, it is also important that teachers realize that having this type of synergy is important and that they make it an explicit goal for the enactment of the curriculum. This makes synergy a conceptual pattern that can guide practice as well as design.

CONCLUSION

I have argued that harnessing a collection of artifacts, agents, and activity structures is a current trend in educational research that views learning as the appropriation of disciplinary ways of knowing, doing, and talking. I posit that this approach is consistent with the scaffolding metaphor but that there is value in adopting a new term, distributed scaffolding (following Puntambekar & Kolodner, 1998, in press), to describe this approach. Synthesizing my own and others' work, I presented three nonexclusive patterns of distributed scaffolding that appear to emerge in existing designs: differentiated scaffolds in which different needs are met by different supports, redundant scaffolds in which a collection of supports addresses the same need, and synergistic scaffolds in which a collection of supports is coconstituted to support the same need.

In identifying synergy as a pattern of distributed scaffolding, I suggest that the principled design of distributed scaffolding should include an attempt to create cohesion and direct interaction between the elements of the scaffolding system. Materials should share the same framework, task structure, and language. Discussions concerning the process of activities should be anchored in the activities and point as closely as possible to the material and conceptual tools that are used in the domain vis-à-vis the activity. Another important implication is that the teacher plays a key role in integrating the elements of the system.

As I have noted, this notion of a system of scaffolds comes hand in hand with novel learning environments that try to position students as active members of learning communities engaged in constructing meaningful and defensible knowledge claims. The magnitude of the challenge that these goals have created has demanded and resulted in scaffolding systems that bridge students' current and envisioned proficiency but that are quite complex and require a certain level of knowledge and skill to realize their potential. For example, software tools to analyze and synthesize primary data are specially designed to structure and problematize (Reiser, this issue) students' inquiry processes (for perspectives on principled design, see Quintana et al., this issue; Sherin et al., this issue). One needs to become adept at using these tools in and of themselves to manipulate data and make sense of particular problems or questions, which can be quite a feat. Yet, one also needs to come to see the underlying disciplinary conventions that these tools embody to appropriate the cultural tools of the discipline.

There seems to be an intricate balance between providing guidance and introducing new forms of complexity. One important target for designing toward synergy is the inclusion of scaffolds that facilitate the use of other tools and supports. Teachers in particular can make a significant contribution by demonstrating how to use the tools in ways that are consistent with the practices and values that govern the discipline.

There is a growing consensus that there is a need for multiple scaffolds to address the complexity of appropriating disciplinary ways of knowing, doing, and talking (Bell & Davis, 2000; Edelson et al., 1999; Krajcik et al., 2000; Lehrer & Schauble, 2000; Linn & Hsi, 2000; Puntambekar & Kolodner, 1998, in press; Reiser et al., 2001; Snir & Smith, 1995; Tabak & Reiser, 1997; White, 1993). Yet there are still many open questions concerning how the different elements contribute to learning, interact, and work as a system. As such systems of scaffolds continue to become objects of study, I hope that educators will more fully understand how they foster learning.

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