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Tools for Scaffolding Students in a Complex Learning Environment: What Have We Gained and What Have We Missed?

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This article discusses the change in the notion of scaffolding from a description of the interactions between a tutor and a student to the design of tools to support student learning in project-based and design-based classrooms. The notion of scaffolding is now increasingly being used to describe various forms of support provided by software tools, curricula, and other resources designed to help students learn successfully in a classroom. However, some of the critical elements of scaffolding are missing in the current use of the scaffolding construct. Although new curricula and software tools now described as *scaffolds* have provided us with novel techniques to support student learning, the important theoretical features of scaffolding such as ongoing diagnosis, calibrated support, and fading are being neglected. This article discusses how to implement these critical features of scaffolding in tools, resources, and curricula. It is suggested that if tools are designed based on the multiple levels of the student understanding found in a classroom, tools themselves might be removed to achieve fading.

In the past few years, the notion of scaffolding has been an issue of discussion. Stone (1998a) provided an insightful critique of the "metaphor of scaffolding" and called for enriching the scaffolding metaphor, especially as it applied to the field of learning disabilities. As a response to his article, Palincsar (1998) pointed out that it is the "*atheoretical* use of scaffolding that has become problematic" (p. 370). She urged researchers in the field to consider "repositioning the metaphor in its theoretical framework," "consider ways in which contexts and activities scaffold learning," and "research the relationship between scaffolding and good teaching" (p. 1). In this article, we reiterate that recommendation, especially for researchers designing tools for students to learn productively in complex environments such as classrooms.

In its original use (Bruner, 1975), scaffolding described interactions between a parent and a child or between a tutor and a student. The adult (parent, tutor) provided just enough support based on the progress made by the child on an ongoing basis. With an increase in project-based and design-based environments for teaching science and math in the context of a classroom, the notion of scaffolding is now increasingly being used to describe the prompts and hints provided in tools to support learning. Scaffolding is no longer restricted to interactions between individuals—artifacts, resources, and environments themselves are also being used as *scaffolds.* Support is now being provided in paper-and-pencil tools (Puntambekar & Kolodner, 2002), technology resources (Bell & Davis, 1996; Jackson, Krajcik, & Soloway, 1998), peer interactions (Puntambekar, Nagel, Hübscher, Guzdial, & Kolodner, 1997), or teacher-led discussions (Tabak & Reiser, 1997). As such, the scaffolding construct is being applied more broadly, to include the support provided in technology tools, peer interactions, and discussions aimed at the whole class. Although the original description of scaffolding does little to explain the multifaceted nature of supporting learning in the complex environment of a design or project-based classroom, we believe that the scaffolding construct is increasingly being used synonymously with support.

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By broadening its scope, the scaffolding construct has been overgeneralized and has therefore been stripped of its original meaning.

This article discusses traditional and current instantiations of the scaffolding construct, what we have gained and missed in the current implementations of scaffolding, and ways to scaffold students in a complex learning environment. We argue that although the new curricula and software tools now described as scaffolds have provided us with novel techniques to support student learning, the important features of scaffolding such as ongoing diagnosis, calibrated support, and fading are being neglected. We provide suggestions about how to implement these critical features of scaffolding in tools, resources, and curricula. We suggest that if tools are designed based on the multiple levels of the student understanding found in a classroom, tools themselves might be removed to achieve fading.

We have divided this article into three sections. In the first, we discuss the key features of scaffolding based on the historical and theoretical roots of the construct. In the second section, we review research that purports to design and implement scaffolding to help students (mainly in a classroom) learn better. In the final section, we provide suggestions to implement some of the key elements of scaffolding in a classroom.

KEY FEATURES OF SCAFFOLDING

Scaffolding was defined by Wood, Bruner, and Ross (1976) as an "adult controlling those elements of the task that are essentially beyond the learner's capacity, thus permitting him to concentrate upon and complete only those elements that are within his range of competence" (p. 9). The notion of scaffolding has been linked to the work of Soviet psychologist, Lev Vygotsky. Although Vygotsky did not use the term scaffolding, he believed that learning first occurs at the social or interindividual level, and emphasized the role of social interactions as being crucial to cognitive development. Therefore, according to Vygotsky (1978), a child (or a novice) learns with an adult or a more capable peer; and learning occurs within the child's zone of proximal development (ZPD). ZPD is defined as the "distance between the child's actual developmental level as determined by independent problem solving and the higher level of potential development as determined through problem solving under adult guidance and in collaboration with more capable peers" (Vygotsky, 1978, p. 86). Enabling the learner to bridge this gap between the actual and the potential depends on the resources or the kinds of support provided. As Stone (1998a) pointed out, the original description of scaffolding by Wood et al. was largely pragmatic and not clearly linked to the theoretical notion of the ZPD, and it was later (Bruner, 1985; Cazden, 1979) that the notion of scaffolding was linked with the ZPD. Instruction in the ZPD then came to be viewed as taking the form of providing assistance (or scaffolding), enabling a child or a novice to solve a problem, carrying out a task or achieving a goal that he or she would not be able to achieve on his or her own. According to Greenfield (1999)

> The scaffold, as it is known in building construction, has five characteristics: it provides a support; it functions as a tool; it extends the range of the worker; it allows a worker to accomplish a task not otherwise possible; and it is used to selectively aid the worker where needed. (p. 118)

This analogy embodies two important elements of instructional scaffolding. Instructional scaffolding enables a child or a novice to solve a problem, carry out a task, or achieve a goal that he or she cannot accomplish on his or her own (Wood et al., 1976); and describes a support that can easily be removed when no longer needed. However, an important difference that Lepper, Drake, and O'Donnell-Johnson (1997) pointed out is that this analogy also "carries an inappropriate connotation" that the student, much like the worker or the painter, will return to ground zero when scaffolding is removed. Lepper et al. pointed out that a more suitable analogy is that of a tunnel or an arch being supported by a temporary structure while it is under construction. This support is later removed when construction is complete and the tunnel or arch can stand on its own. Although an appropriate analogy can be a matter of debate, the important aspect of scaffolding is the support that an adult or expert provides to the learner, until the learner is capable of performing independently *after* the support is removed.

The original notion of scaffolding assumed that a single, more knowledgeable person, such as a parent or a teacher, helped an individual learner by providing him or her with exactly the help he or she needed to move forward (Bruner, 1975; Wood et al., 1976). In this description, one of the most critical aspects of scaffolding is the role of the adult or the expert. Wood et al. documented six types of support that an adult can provide: recruiting the child's interest, reducing the degrees of freedom by simplifying the task, maintaining direction, highlighting the critical task features, controlling frustration, and demonstrating ideal solution paths. The expert is a domain expert as well as a facilitator who is knowledgeable of the skills, strategies, and processes required for effective learning. The expert not only helps motivate the learner by providing just enough support to enable him or her to accomplish the goal, but also provides support in the form of modeling, highlighting the critical features of the task, and providing hints and questions that might help the learner to reflect (Wood et al., 1976). In this conception, the adult's role includes perceptual, cognitive, and affective components (Stone, 1998a).

Central to successful scaffolding is the notion of a shared understanding of the goal of the activity. Although some elements of the activity may be beyond what the child could accomplish in working alone, *intersubjectivity* (Rogoff, 1990; Wertsch, 1985), or a shared understanding of the activity, is considered critical. Intersubjectivity is attained when the adult and child collaboratively redefine the task so that there is combined ownership of the task and the child shares an understanding of the goal that he or she needs to accomplish. The adult or expert's role is to ascertain that the learner is invested in the task as well as to help sustain this motivation, "making it worthwhile for the learner to risk the next step" (Wood et al., 1976, p. 98).

A second key element of scaffolding is that the adult provides appropriate support based on an *ongoing diagnosis* of the child's current level of understanding. This requires that the adult should not only have a thorough knowledge of the task and its components, as well as the subgoals that need to be accomplished, but should also have knowledge of the child's capabilities that change as the instruction progresses. Wood et al. (1976) stated:

> The effective tutor must have at least two theoretical models to which he must attend. One is a theory of the task or problem and how it may be completed. The other is a theory of performance characteristics of the tutee. Without both of these, he can neither generate feedback nor devise situations in which his feedback will be more appropriate for *this* tutee, in *this task* at *this* point in task mastering. The actual pattern of effective instruction then, will be both *task* and *tutee* dependent, the requirements of the tutorial being *generated* by the interaction of the tutor's two theories. (p. 97)

The ongoing diagnosis thus leads to a "careful calibration of support" (Stone, 1998a) so that the adult is able to provide "graduated assistance" of different types. The adult draws from a repertoire of methods and strategies to provide support, constantly fine tuning the support based on the child's changing knowledge and skills. Therefore, the amount and types of strategies are different not only for different learners who are at different levels in their learning, but also for the same learner over a period of time. The adult may model the ideal solutions (Wood et al., 1976) or the appropriate strategies (Palincsar & Brown, 1984) or provide several types of support such as offering explanations, inviting participation, modeling desired behavior, and providing clarifications (Roehler & Cantlon, 1997).

An important point is that the ongoing assessment and adaptation of support is attained through the *dialogic and interactive* nature of scaffolded instruction. As Newman, Griffin, and Cole (1989) pointed out, "the appropriation process is reciprocal" (p. 58). Although the teacher plays a vital role in the instructional process, the child is also an active participant so that scaffolded interactions are a function of participation by the teacher and the learner. The dialogic interactions (Reid, 1998), such as the ones in the reciprocal teaching studies (Brown & Palincsar, 1985; Palincsar & Brown, 1984), enable the teacher to conduct an ongoing assessment of the student's understanding and allow the student to play a role in negotiating the interactions. Interactions also enable the adult to monitor progress, provide appropriate support, and eventually fade the support so that the learner is now able to function on his or her own.

The final key theoretical feature of scaffolding is fading the support provided to the learner so that the learner is now in control and taking responsibility for learning. Vygotsky (1978) theorized that the cognitive processes that first occur on an interpsychological plane move on to an intrapsychological plane, a process that he called *internalization.* There is a transfer of responsibility from the teacher to the learner and the scaffolding can be removed, as the learner moves toward independent activity. According to Vygotsky, internalization is hardly a mechanical operation. In Wood et al.'s (1976) original inception, what is important about the transfer of responsibility is that the child not only learns how to complete a specific task, but successful scaffolding entails that the child also abstracts the *process* of completing the particular activity to generalize this understanding to similar tasks.

Early studies that described scaffolding were mainly observation studies—*quasinatural,* as Stone (1998a) called them—rather than being interventions. Whether the studies involved parent–child interactions such as those described by Greenfield (1999) in which she analyzed the interactions of Mexican mothers teaching their daughters to weave or the components of classroom interactions discussed by Langer and Applebee (1986), the studies provided descriptions of observed interactions.

One of the earliest intervention studies of scaffolding is that of Wood et al. (1976). In Wood et al.'s study, 3-, 4-, and 5-year-olds engaged in a task of building a pyramid from interlocking blocks. Each child was tutored individually, and the tutor followed a set of guidelines for her tutoring. The tutor responded to the child's actions—for example, if the child successfully assembled a pair, the tutor encouraged him or her to make more of the same; if the child was assembling pieces on his or her own and ignored an element, the tutor would draw the child's attention to it. Tutorial intervention took the form of direct assistance by modeling, a verbal prompt to help the child think about the task, a verbal direction, or a reminder. Ongoing diagnosis and careful calibration of support was evident as the tutor's response was contingent on what the child accomplished at any particular time. In this study, although younger children needed more help, it is interesting that the tutor did not always follow preset rules in her interactions, especially with 4-year-olds, and adapted her tutoring to the changing behaviors of the child; thereby providing just enough assistance to help the child move forward—assistance that was sensitive to the child's progress.

Perhaps the most well-known intervention of scaffolding in the classroom is the work on reciprocal teaching (Brown & Palincsar, 1985; Palincsar & Brown, 1984). According to Brown and Palincsar, "the procedure we developed is a form of expert scaffolding" and "reciprocal teaching is a form of expert scaffolding in the classroom" (p. 86). Palincsar and Brown's study helped students with four comprehension monitoring strategies—self-directed summarizing (review), questioning, clarifying, and predicting. Learning took place in an interactive environment in that the teacher and the students both took turns in the process. Intersubjectivity was achieved by getting students to be informed participants who understood the value and use of the strategies. The teacher modeled the strategies to make them overt, explicit, and concrete. If the passage was new, the teacher helped to draw the students' attention to the title, discussed its relation to prior knowledge, and asked for predictions about the title. The responsibility for the comprehension monitoring activities was gradually transferred to the students. As students became more competent, one of the students acted as a "leader" to guide the others. The leader summarized the content of the passage, clarified any difficulties, asked a question, and predicted what could come next. Feedback was provided to help students move toward competence.

These early interventions highlight how the key features (viz., intersubjectivity, ongoing diagnosis, tailored assistance, and fading) were attained in the dynamic, interactive environment. Although Wood et al.'s (1976) study illustrated the tutorial interventions in a one-on-one situation, the reciprocal teaching studies were conducted with small groups of learners in a classroom. In these studies, both the quality and the quantity of support were varied, based on the needs of a particular learner, or for learners with different needs. As learners attained competence, the scaffolding was faded, giving them more control.

TOOLS TO SUPPORT STUDENT LEARNING

With an upsurge in project-based and design-based approaches to help students learn science and math (Kolodner, 1997; Kolodner et al., 2003; Reiser et al., 2001), the notion of scaffolding is now increasingly being used to describe the support provided in tools to help students learn successfully. However, classroom situations involving many students do not allow for the fine-tuned, sensitive, personalized exchange that occurs in one-on-one or small-group scaffolding (Rogoff, 1990). Therefore, instead of one teacher working with each student, support is now being provided in a paper or software tool that individuals interact with, or classroom activities are being redefined so that peers can help each other.

Tools and resources including curricula and artifacts are all being used to support student learning in classrooms. Tools and resources are being used not only for demonstrating relevant aspects of the task or strategies and making covert processes visible (Linn, 1998), but also for promoting peer interactions. These tools are being described as scaffolds or as providing scaffolding. However, are these capturing the theoretically critical features of scaffolding as described in the previous section?; or has the notion of scaffolding been overgeneralized? In this section, we discuss how tools (especially computer-based tools) and resources including curricula and artifacts map on to the original tenets of scaffolding. Specifically, we discuss three issues:

- Curricula that aim to create a shared understanding among a whole class of students.
- Tools that offer structure and support for completing a task, but often do not address the critical features of ongoing diagnosis, graduated assistance, and fading.
- Tools that promote peer interactions to enable peers to support each other's learning.

Shared Understanding

As previously discussed, an important feature of scaffolding is the shared understanding of a common goal that provides motivation to students to engage in the task. Langer and Applebee (1986) referred to the notion of ownership—"they [students] must see the point of the task, beyond simple obedience to the teacher's demands" (p. 185). Although this shared understanding of the goal was achieved between the adult and the child in the original notion of scaffolding, it is now important for the whole class or a group of learners to share the goal and have ownership of the task so that they are motivated to learn. Shared understanding in a classroom environment is achieved in the Biology Guided Interactive Learning Environment (BGuILE) project through staging activities (Reiser et al., 2001). BGuILE includes technology-rich curriculum units that focus on helping students construct explanations of complex scientific phenomena based on data-driven investigations. The staging activities in the BGuILE curriculum are investigations that prepare students by providing them with smaller data sets to enable them to tackle larger and more complex data sets. Similar to reciprocal teaching, the staging activities start with the teacher modeling the activities and slowly transferring the responsibility to the students. Another interesting approach to attain shared understanding is used in the Learning by Design™ (LBD) curriculum. LBD (Kolodner et al., 2003) is an approach to science learning in which middle school students engage in design projects such as designing a car that can travel on different terrains to help them learn about the physics of forces and motion. As students engage in their designs, they need to learn several skills such as redefining the problem, generating ideas for their designs, making predictions, testing their designs, evaluating, and redesigning, to name a few. In addition they need skills such as collaborating with other group members, articulating and justifying their ideas, and so forth. In early LBD implementations, it was found that it is not easy for students to engage in these activities. Therefore, a launcher unit was created (Holbrook & Kolodner, 2000) to help students ease into the larger LBD units. In the launcher unit for physical science, students watch parts of the movie, *Apollo 13,* and discuss how the scientists worked together both before the launch of the spacecraft and when the mission was endangered. The launcher unit prepares students for the larger LBD units by enabling them to perform less complex activities and supports the building of skills such as collaboration, articulation, critiquing, and so forth. Both the staging activities and the launcher unit help students to experience simplified versions of the complex activities. They prepare students for more difficult activities and create a shared understanding of the goals of the curriculum, set expectations, provide motivation, and also provide training in the necessary skills that students may not be familiar with. They also prepare the teacher to become familiar with their "new practices as modelers, coachers & facilitators" (Kolodner et al., 2003, p. 513).

Ongoing Diagnosis, Graduated Assistance, and Fading

Although shared understanding of goals and practices has been achieved in some tools, the issues of ongoing diagnosis and fading are more challenging because they require tools that are dynamic and that provide adaptive support. In this section, we discuss software tools that provide structure and help students with strategies for better learning, as well as tools that are designed to promote peer interactions. We argue that although these tools are described as providing scaffolding, they do not do so because they are static and do not adapt to the student's skills and knowledge.

Tools that provide structure for complex tasks. Approaches to science learning have long emphasized the need to help students through the process of scientific inquiry. Quintana et al. (2002) summarized three challenges that learners face: (a) process management (i.e., the ability to engage in processes and activities required for inquiry); (b) sense making, which they describe as difficulties that learners experience in making sense of their work and finding a direction; and (c) articulation. Several software tools have been developed in the past few years to help students with these difficulties: ThinkerTools (White & Fredriksen, 1998), STAR LEGACY (Schwartz, Lin, Brophy, & Bransford, 1999), Knowledge Integration Environment (KIE; Linn, 1995), Progress Portfolio (Loh et al., 1998), BGuILE (Reiser et al., 2001), and Model-It (Jackson et al., 1998), to name a few. It is beyond the scope of this article to review all of the software tools designed for science learning. Instead, our discussion focuses on tools that specifically address the issue of scaffolding student learning. We discuss studies that illustrate the current use of the notion and compare them to the original notion of scaffolding.

One of the most widely used mechanisms for providing support is based on the notion of making the tacit explicit, whether in the form of providing support for a process or a task or by providing graphical representations. For example, the KIE (Linn, 1995) consists of a suite of tools to help foster knowledge integration by developing skills such as reflection, critiquing, and using evidence to develop an argument. KIE is based on the notion of "scaffolded knowledge integration" (Linn, 1995; Linn, Songer, & Eylon, 1996), "where students are scaffolded, or supported, as they integrate their ideas" (Bell & Davis, 2000, p. 143). As students work on KIE projects, they receive prompts to help them through the process of building an argument backed by claims (Bell & Davis, 2000).

One of the tools from KIE, the Sensemaker, helps students develop scientific arguments by supporting the process of constructing an argument. Sensemaker makes the process visible and encourages students to reflect on the process. Another component of KIE is the support provided by an online guidance system, titled Mildred. This tool provides students with support at four levels—the big picture, what to do, how to do it, and things to think about. The prompts in KIE include activity hints (specific prompts to help students in making decisions), evidence hints, and metacognitive or self-monitoring hints (Bell & Davis, 1996). Such hints and questions are described as being important as students reflect on their own or to promote dialogue when students work in small groups.

KIE has been used extensively in middle schools. Bell and Davis (2000) reported that the prompts in KIE helped students to link evidence with theory and that the percentage of responses indicative of "causal warrants" was higher than merely descriptive responses when students used the support provided in KIE. Studies by Davis (2003) in which generic and specific prompts for reflection were compared, found that there was greater evidence of reflection in students receiving generic prompts as compared to the ones who received directed prompts.

The notion of making tacit processes explicit is also echoed in BGuILE (Reiser et al., 2001) in which data-driven explanations and investigations are fostered. The BGuILE project provides middle and high school students with opportunities to engage in complex scientific investigations using technology-rich curricula. Students learn to investigate scientific claims and link claims to evidence using primary datasets. Students use technology tools and study quantitative data to construct explanations for complex scientific phenomena. Reiser (2002) described two mechanisms of scaffolding—structuring and problematizing. Structuring the task involves providing students with tools and workspaces that provide the structure necessary to make an open-ended task more manageable. Problematizing involves forcing the students to confront the complexities of a task, such as providing a menu to have students examine the data to construct valid explanations. The Galapagos Finches is a tool in the BGuILE environment that helps learners understand principles of ecology by making the key strategies explicit (Reiser, 2002). It enables students to make comparisons across time or across specific traits to understand a particular population and articulate their reasoning for data comparison. Studies using the Galapagos Finches environment have shown that students have been able to use data to provide scientific explanations of phenomena and understand key scientific ideas (Reiser, 2002).

ExplanationConstructor (Sandoval, 2003), another tool in the BGuILE environment, provides support during students' investigations. This tool helps students to keep an ongoing electronic journal in which they can explain their findings based on the questions provided, using the evidence that they collect as they engage in investigations, such as the Galapagos Finches. ExplanationConstructor includes prompts that serve as "epistemic and conceptual scaffolds" (Sandoval, 2003), enabling students to construct explanations that are supported with data from their investigations. In studies with high school students using this tool, Sandoval used "causal coherence" as a measure of connectedness of the causal relations in students' explanations. It was found in these studies that prompts in ExplanationConstructor helped students to construct explanations supported by theory. Sandoval made an interesting point that because of the limited interactivity, the value of using the software programs may be limited in helping students interpret data or in figuring out "whether their claims make sense" (p. 45).

Visualization and modeling. The visualization capabilities afforded by technology tools have been used to help students learn complex scientific phenomena in the WorldWatcher environment (Edelson, 2001; Edelson, Gordin, & Pea, 1999). WorldWatcher is based on the notion that expert scientists have tacit knowledge that they bring to understand scientific procedures, knowledge that high school students lack. WorldWatcher makes this knowledge explicit by providing students with visual representations of scientific phenomena such as climate change. The environment supports data visualization and data analysis in which students can manipulate geographic data by changing the visual features of the maps and also by performing statistical analyses. In the Create-a-World project, WorldWatcher was used with another tool, Progress Portfolio (Loh et al., 1998), to support reflective inquiry.

As students work on an investigation, they use the Progress Portfolio software to create pages that can contain images, data, and text entries, as well as annotations. The pages can be organized either thematically or chronologically. The Progress Portfolio environment prompts students to formulate research questions and provides them with a "data camera" tool to grab images related to their research questions, annotate the data, and prepare a presentation. In addition, students can explore relations by making comparisons across pages or organizing pages into clusters. Progress Portfolio also provides a presentation mode for students to communicate their results. A teacher mode allows teachers to customize templates of pages.

Another tool that uses visualization is Model-It (Jackson et al., 1998). In the classical description of scaffolding, an adult or a more capable peer provided tailored assistance within the ZPD, based on an ongoing assessment of the learner. This support was faded as the learner became more capable. With advances in technology, software tools are now being built to help achieve these functions. As noted by Jackson et al. (1998), "building scaffolding into software offers the opportunity to support diversity through individualized support that accommodates learners of different skills, backgrounds and learning styles, and growth through options that provide more powerful functionality as the learner develops expertise" (p. 187). Model-It, a tool based on learner-centered design (Soloway, Guzdial, & Hay, 1994), helps students build computer models of complex systems or phenomena by supporting them through the process of model building. Model-It enables students to build dynamic models by providing them with three modes: plan, build, and test in which they define objects, variables, and the relations between them. Three types of scaffolding are built into Model-It—supportive scaffolding, reflective scaffolding, and intrinsic scaffolding. Supportive scaffolding refers to specific help that the students are provided in the form of examples, what to do next hints, and so forth, to help complete a task. In Model-It, fading of supportive scaffolding is accomplished by a simple mechanism—a "stop reminding me" button that the student can choose when he or she does not need the hints. Therefore, fading is not automatic but has to be explicitly initiated by the student. However, the prompting mechanism is reactivated if the learner continues to neglect an activity after stopping the reminders. The coaching and modeling functions are described as "passive scaffolds" in that they are activated by help buttons, so that a student can ask for contextualized help or ask for an example. Reflective scaffolding promotes reflection on the task by providing prompts in a notepad window where students can input text. In a series of studies, Jackson, Krajcik, and Soloway (2000) found that high school students could successfully build models using the tool; they also turned off the supportive features and used more advanced features of the software as they developed expertise.

In more recent work on Model-It, Fretz, Wu, Zhang, Krajcik, and Soloway (2002a, 2002b) discussed three types of scaffolds in Model-It—"the process map scaffold," which provides structure for the process by decomposing the task; the "articulation text box," which provides support for articulating explanations; and the "dynamic testing scaffold," which supports students by providing multiple representations that are manipulable. Fretz et al. (2002a, 2002b) found that the support in Model-It helped students with the plan–test–build process in building a model. They also found that the process map helped learners with the modeling task, and the articulation text box helped facilitate discussions in student pairs.

Peer support. To provide more interactivity and "on-demand" guidance, the notion of peer support has also been explored in some current learning environments. Brown et al. (1993) emphasized the multidimensional nature of the interactions in a classroom where students

> of all ages and levels of expertise and interests seed the environment with ideas and knowledge that are appropriated by different learners at different rates, according to their needs

> and to the current states of the zones of proximal development in which they are engaged, (p. 193)

To support the occurrence of discourse among students in a classroom, several computer-based discussion tools are now being used. Tools such as CSILE (Scardamalia & Bereiter, 1994), WebSMILE (Guzdial et al., 1997), and Speakeasy (Hoadley & Linn, 2000) provide opportunities for asynchronous discussions. These tools have been found to help students delve deeper into important scientific issues (Scardamalia & Bereiter, 1994), to provide more scientific justifications for their designs (Puntambekar et al., 1997), and to generate conceptually richer elaborations (Hsi & Hoadley, 1997). As students engage in dialogue and negotiation in a knowledge-building discourse (Scardamalia & Bereiter, 1994), the more knowledgeable peers contribute by raising important issues, pointing to resources, and by providing clarifications. Less knowledgeable members play an important role by bringing up questions and asking for clarifications.

Tools That Scaffold Learning: What Have We Gained and What Have We Missed?

Software tools that provide procedural support are an important first step in designing scaffolding. They address the important pedagogical issue of helping students in a complex task by constraining the task itself, providing a structure for organizing arguments and scientific explanations, or by making the scientific process more transparent. Further, they also provide assistance to the teacher in the classroom who cannot work with all the groups at all times. When a tool provides structure for a task, students can work with the tool and move forward in the inquiry process leaving the teacher free to work with students who might need more help. However, the description of scaffolding in the tools discussed signals a change in the way the scaffolding construct has been used in recent years.

Table 1 summarizes the change in the notion of scaffolding, from the traditional use of the construct to the more recent use of the term. The change reflects the fact that the support in tools is specifically designed for helping students in the complex environment of the classroom; therefore, tools, resources, and curricula embody multiple modes of support with varied affordances for each. As described in the table, this change has occurred in the key elements of scaffolding (i.e., establishing a shared goal, the nature and expertise of the scaffolder, ongoing diagnosis, and fading).

One of the major changes is in the way of establishing a shared understanding of a common goal in which students in a classroom as well as the teacher work together on smaller, less complex units built into the curriculum. Resources such as the launcher unit and the staging activities are excellent examples of achieving shared understanding in a classroom and demonstrate how this feature can be adapted in a situation that is different from one-on-one teaching. Not only do these resources provide motivation, but they also help students learn the necessary skills in the context of less complex tasks.

Changes have also occurred in the role of the scaffolder. Instead of a single, knowledgeable person providing support, we now have tools and resources, peers, or the learning environment itself providing support to students. In recent years, there has been a definite advancement in designing the types and techniques of providing support in a complex learning environment, especially with the help of technology tools. Although there might have been limitations to the types and amounts of scaffolding that a single individual can provide to a whole class of students, recent approaches have been instrumental in broadening the scope by designing multiple modes by which support can be provided. From the multiple types of hints in the KIE environment to the conceptual and epistemic supports in ExplanationConstructor, from the visualizations in WorldWatcher to visual aids for modeling in Model-It, there is a rich array of sophisticated forms of support to help students in a classroom engage productively in complex tasks.

However, the support for the scientific process provided in the tools discussed earlier focuses on providing "blanket support" (i.e., the amount and type of support is constant for ev-

TABLE 1
Evolution of the Notion of Scaffolding

Feature of Scaffolding	*Original Notion of Scaffolding*	*Evolved (Current) Notion of Scaffolding*
Shared understanding	• Adult or expert establishes shared understanding of common goal and provides motivation	• Authentic task often embedded in the environment; provides a shared understanding
Scaffolder	• Single, more knowledgeable person provides support to complete the task	• Assistance is provided; tools and resources
	• Multimodal assistance provided by a single individual	• Distributed expertise—Support is not necessarily provided by the more knowledgeable person, but by peers as well
Ongoing diagnosis and calibrated support	• Dynamic scaffolding based on an ongoing assessment of the learner (individual)	• Passive support—Ongoing diagnosis by peers and or software is not necessarily undertaken
	• Adaptive scaffolding—Support is calibrated and sensitive to the changing needs of the learner	• Blanket "scaffolding"—Support (especially in tools) is the same for all students
Fading	• Eventual fading of scaffolding as students become capable of independent activity	• In most cases, support is permanent and unchanging

eryone and is not sensitive to the changing level of understanding in learners). Merely providing students with a visual interface or structure for a process cannot be described as scaffolding unless the hints and prompts are *contingent* on an ongoing diagnosis of student learning.

One of the most essential aspects of cognitive growth through scaffolding is that the more competent individual (the tutor) adapts to the evolving knowledge and skills of the less competent individual (the tutee). This results in interactions that are different in content and form from individual to individual (Hogan & Tudge, 1999). As Wood et al. (1976) described, scaffolded interactions are comprised of a theory of the task and a theory of the tutee. The tools discussed earlier are no doubt based on theories of the task, albeit fairly course-grained theories that address the difficulties that students have in scientific inquiry. Although this is by no means trivial, we would like to emphasize that a critical element of providing scaffolding is that tutorial interactions are generated by an interaction of the theory of the task and the theory of the tutee, creating support that is relevant to a particular tutee at a particular time; support is therefore contingent on an ongoing diagnosis of the learner. Tools that are permanent and unchanging, in which the theory of the tutee is not updated based on the interactions, lack two all-important aspects of scaffolding: ongoing diagnosis and calibrated support.

Having peers work with and support one another does not adequately address the issue of providing support based on students' ongoing understanding either. Although group work and electronic discussion tools provide opportunities for peer interactions, students working with one another do not necessarily think about "intentionally" attuning their support to the changing level of understanding of their partners or other members of the group. One of the most important characteristics of scaffolding is its bidirectional, dialogic nature. Although dialogue is a critical part of peer interactions, the dialogue may not be focused on adjusting the support that one student might provide to another. Rogoff (1990) pointed out some interesting shortcomings in the sensitivity and effectiveness of the scaffolding provided by peers as opposed to adults. She maintained that peer interactions may encourage exploration, performance, and can provide motivation; in a classroom environment, peers can be critical of each other and force each other to think. Expert–novice interactions, on the other hand, are marked by an assessment of the partner's level of competence so that support can be tailored to specific needs, which is not possible in peer interactions.

Tudge (1990, 2000), who studied the effect of competence and confidence in peer interactions, found that less competent peers who received feedback from materials improved more than those who did not. Tudge (2000) found that peer interactions could actually deteriorate if a partner was competent but less confident. In their studies with Model-It, Fretz et al. (2002a, 2002b) also found that peer support was too low level and hence not very helpful. Therefore,

> There is no guarantee that the meaning that is created when two peers interact will be at a higher level, even if one child is more competent than another and is providing information within the less competent peer's zone of proximal development. Rather than casually assuming the cognitive benefits of pairing a child with a more competent peer, we should pay more attention to the processes of interaction themselves. (Tudge, 1990, p. 169)

Even if peers are learning together, co-construction of a zone of proximal development might be difficult when a more advanced peer is interacting with a less advanced partner because, "even if a peer knows what the less advanced child needs, he or she may have difficulty adjusting to an appropriate level and adjusting as the child improves over time" (Hogan & Tudge, 1999, p. 57).

The final issue is that of fading the support as the learner becomes capable of independent learning. Tools that provide static support, or passive scaffolds, contradict the essence of the scaffolding construct by overlooking the change from "other" to self-regulation. Relying on students to get the help they need, or providing passive supports that fade because students stop using them, do not give an indication of whether students have internalized the skills. Studies on metacognition and self-regulation have shown that not all students are capable of monitoring and regulating their learning and seeking help when they need it (Hadwin & Winne, 2001). Students, especially novices, might neglect the help that is given or may not be able to judge when they need help (Aleven & Koedinger, 2000). Studies by Land and Zembal-Saul (2001) found that making thinking visible or the process explicit does not necessarily mean that students use the support meaningfully. In a classroom study using Progress Portfolio, Land and Zembal-Saul, found that successful learning with the software was contingent on the background knowledge of the learners as well as students' ability to monitor their understanding. Good scaffolding implies that a learner is provided with support that can enable him or her to function independently. The best scaffolding can be faded because it will eventually lead the learner to internalize the processes he or she is being helped to accomplish (Rogoff, 1990). Therefore, it is important to understand how students are using the tools and whether they are actually able to work independently when the tool is removed.

To summarize, there are two main facets to the change in the scaffolding construct. First, there has been enrichment in the techniques of providing support; and second, in current implementations there is a lack of emphasis on the process. Although there have been important developments in designing tools, the key features of the process of scaffolding (viz., ongoing diagnosis, calibration, of support, and fading) are missing in the current implementation of the scaffolding construct.

At its core, the scaffolding construct is indicative of a process whereby a learner is supported in various ways so that he or she can function independently when the support is removed. Although the tools developed to provide support have enriched our understanding of the types of support that should be provided to students learning complex domains, there is a lack of attention to the process of scaffolding. Stone (1998b) described the following:

> In enriching our understanding of scaffolding, it is important that we keep in mind two interrelated points. First, the term scaffolding serves both as a noun and a verb (Oxford English Dictionary, 1989 [as cited in Simpson & Weiner, 1989]). There are entities that serve as scaffolds, such as diagrams, and these entities serve an important role in instruction. However, what is most crucial is the process by which these entities are used to foster new understandings. In essence, one could argue that the core of the scaffolding metaphor rests squarely on viewing it as a process. (p. 412)

MOVING FORWARD WITH DESIGNING SCAFFOLDING IN A COMPLEX ENVIRONMENT

Educational researchers are now increasingly recognizing the need for developing contextualized theories of learning and teaching that can lead to "usable knowledge" (Lagemann, 2002). The contexts of a modern classroom are considerably different from the one-on-one situations in which scaffolding has been originally provided. To develop an enriched notion of the scaffolding construct that is relevant to the classroom context inevitably requires changing it to fit the current needs; however, it is important that we do not overlook the essential features and the theoretical roots of the construct. We call for a principled approach to the design and analysis of the learning supported by the tools in the classroom context to develop a contextualized theory of the scaffolding construct.

We discuss three suggestions to move toward building and understanding scaffolding in a classroom environment. Our first suggestion is to take into consideration the multiple ZPDs in a classroom when designing tools. Second, we discuss building fading into the whole environment (rather than each tool) so that the tools themselves might be removed when students do not need them anymore. Third is the orchestration of the classroom environment so that all tools and agents play a role in supporting student learning.

The scaffolding construct is embedded in the Vygotskian notion of the ZPD. In the complex environment of the classroom, there are multiple ZPDs that teachers and researchers have to take into consideration while building scaffolding. Once again, going back to Wood et al.'s (1976) original description of a theory of the task and a theory of the tutee as crucial to building effective scaffolding, we need theories of multiple tutees to build scaffolding for a classroom community. Studies that help understand the multiple ZPDs in a classroom will enable the design of a suite of tools based on the ways in which students of different levels of understanding learn. The tools described in the previous section are based on an understanding of the kinds of difficulties that students have during scientific inquiry. However, to move forward, it is important to understand how students who are at varying levels of understanding learn with the help of such tools. Reiser et al. (2001) pointed out that in studies with ExplanationConstructor, "not all students can construct well-grounded explanations" (p. 296). Land and Zembal-Saul (2001) found that one of the conditions that affected learning when students used the computer-based prompts in Progress Portfolio was that the inadequacy of student explanations could go unnoticed unless the teacher worked with them. Studies that examine how students are actually using the tools, and the kinds of learning that the tool promotes in students who are at varying levels of understanding, are important so that support that takes into account the multiple ZPDs in a classroom can be built. Because many of the tools discussed have different kinds of support, it is also crucial that we design studies to understand the role of the various kinds of support, and whether all students need all the kinds of support. If tools are built so that students themselves fade the support when they do not need it, it is important to understand how students are using this feature. Design studies (DBRC, 2003) that collect data and record changes over time are important to iteratively design scaffolding that works in a classroom. Similarly, Hadwin and Winne (2001) pointed out that it is important to collect data over time so that the development of students' ability to regulate their learning can be examined across different contexts.

The central concept of scaffolding is that the support is faded when the learner has internalized the knowledge and skills. Building software tools that eventually fade the support, and building the kind of adaptivity that is seen in intelligent tutoring systems, is difficult and time consuming. In a classroom where many tools are being used to support learning, the tools themselves may be removed as students show evidence of internalization. According to Rogoff (1999), one way to provide scaffolding is to make the messages sufficiently redundant so that if a child does not understand one aspect of the communication, other forms are available to make the meaning clear. When scaffolding is provided in multiple formats, there are more chances for students to notice and take advantages of the environment's affordances. In her studies of weavers in Mexico, Greenfield (1999) also emphasized the importance of the multimodal assistance that mothers provided to their daughters who were learning to weave. In a classroom, it is not possible for one person to provide support for the multiple students learning at different rates within their ZPDs. Building redundancy by designing multiple tools can therefore make up for the lack of graduated assistance in a single tool, if multiple ways and multiple levels of scaffolding are tailored to the multiple ZPDs that are found in any classroom. Rather than looking at a single tool as providing scaffolding, we need to look at a suite of tools as providing scaffolding to students. Therefore, even if a particular tool does not change or fade its prompts, the students may no longer need the tool; thereby, the tool itself may be removed. If different types of scaffolds are built based on the multiple ZPDs that are found in a classroom, then as students make progress, some of the tools may be removed; thereby achieving fading. Although, to build fading, we need to understand whether students are able to function independently and whether the processes that were supported by tools have become part of their repertoire, available for future learning.

The biggest challenge that we face, therefore, is the orchestration of the tools and activities so that the affordances of each are taken advantage of. In a complex classroom environment, it can be difficult to align all the affordances in such a way that students can recognize and take advantage of the many affordances. Therefore, effective scaffolding needs to be distributed, integrated, and multiplied so that students have more chances to notice and take advantage of the environment's and activity's affordances. This requires a careful engineering of the whole environment and the multiple agents therein: teachers, tools, resources, peers, and the curriculum.

To orchestrate all the activities and integrate the tools, the teacher plays the most important role. Brown and Campione (1994) and Brown et al. (1993) discussed the role of the teacher in a classroom that is functioning as a community of learners and is engaged in "guided discovery" as consisting of a delicate balance between guidance and discovery, where the teacher has to constantly make judgments about when to intervene:

> The successful teacher must continually engage in on-line diagnosis of student understanding. She must be sensitive to current overlapping zones of proximal development, where certain students are ripe for new learning. She must renegotiate zones of proximal development so that still other students might be ready for conceptual growth. (Brown et al., 1993, p. 207)

CONCLUSION

In this article, we have discussed how the notion of scaffolding has changed as we have moved into scaffolding classroom communities. As Palincsar (1998) pointed out, scaffolding is a very accessible metaphor because it is flexible and it captures multiple dimensions of teaching and learning, and hence stands the danger of being treated "lightly." We have discussed the main tenets of the original notion of scaffolding and have examined how the notion has been applied to the design of tools in the last 2 decades. Although we now have a better understanding of ways to build support into tools and resources, we seem to have missed some of the key elements of scaffolding such as ongoing diagnosis, adaptivity, and fading. We have discussed some ways in which these features can be built into scaffolding in a classroom environment. As we design more tools and resources to scaffold students in a classroom, we need to further understand what works and what does not work in a classroom. In particular, we need to conduct longitudinal studies to answer questions such as: What are the tools that work best in a classroom? How can we design scaffolds that are based on multiple ZPDs found in a classroom, and how can we fade the scaffolds? Are there strategies (or aspects of the domain) that are best scaffolded by a teacher rather than by a tool? What are the best ways to scaffold domain knowledge? What are the mechanisms by which we can assess that transfer of responsibility has occurred? We need to better understand the learning that is taking place during peer conversations, and during whole-class discussions, to be able to integrate all these activities in a seamless manner. Each of these issues is complex. Building tools that scaffold student learning in a classroom, so that the key theoretical features are not overlooked, is indeed a nontrivial task; and more research is required for an understanding of scaffolding that works in a classroom. Tools such as the ones described in this article are a first step toward designing scaffolding. More research is required so that the support that is static and nonadaptive can be changed to what can truly be described as scaffolding.

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