Scaffolding in Complex Learning Environments: What we have gained and what we have missed

Sadhana Puntambekar

Neag School of Education

University of Connecticut, 249 Glenbrook Road, Storrs, CT 06269-2064

sadhana@uconnvm.uconn.edu

(860) 486 4101

Roland Hübscher

Department of Computer Science and Software Engineering

Auburn University, 107 Dunstan Hall, Auburn, AL 36849-5347

roland@eng.auburn.edu

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Roland Hübscher

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Abstract

In recent years, there has been an upsurge of approaches based on a socio-constructivist framework to help students learn science and math. As such, the notion of scaffolding is now increasingly being used to describe the support provided to students to learn successfully in such environments. In the past two decades, varied approaches to scaffolding student learning have been put forth. Scaffolding has been provided in the form of paper-and-pencil tools, technology resources, peer support or teacher-led discussions. The original notion of scaffolding, as used in the initial studies of parent-child interactions or in teacher-student interactions, seems somewhat narrow to explain the multifaceted nature of learning in complex learning environments, especially when it involves helping an entire class of students learn successfully. However, by broadening the scope of scaffolding, we seem to have missed some of the key features that are crucial to successful scaffolding. While acknowledging that the original notion of scaffolding that described the one-on-one interactions between an adult and child is not adequate for describing the complex nature of learning in a classroom, we emphasize that some of the critical elements of scaffolding are missing in the evolved notion. We discuss the key aspects of scaffolding and how we can design and implement these features in the changed context of scaffolding classroom communities.

Introduction

Few years back, Addison Stone (Stone, 1998) 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" and seems to have occurred "as we have become increasingly comfortable using *scaffold* as a verb." 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". In this paper, we would like to reiterate that recommendation for researchers in the field of the Learning Sciences. As we move forward with the design and implementation of complex learning environments[1], many of which are technology enriched, the notion of scaffolding is now increasingly being used to describe the different kinds of support provided to students. The notion of scaffolding has evolved in the past two decades;

scaffolding is no longer restricted to interactions between individuals – artifacts, resources and environments themselves are also being used as scaffolds.

In the past two decades, varied approaches to scaffolding student learning have been put forth. Scaffolding has been provided in the form of paper-and-pencil tools, technology resources, peer support or teacher-led discussions. Scaffolding in the form of prompts to help students reflect and articulate have been developed (Bell & Davis, 1996; Jackson, Krajcik, & Soloway, 1998; Puntambekar & Kolodner, 2002). Different types of scaffolding, either by varying the activities according to their difficulty or content of the task (Luckin, 1998) have also been designed. For scaffolding to be effective in a complex environment, the complementary roles that tools, resources, teachers and peers play in providing a range of support have been explored (Puntambekar, Nagel, Hübscher, Guzdial, & Kolodner, 1997; Tabak & Reiser, 1997).

The original notion of scaffolding, as used in the initial studies of parent-child interactions (Bruner, 1975) or in teacher-student interactions, seems somewhat narrow to explain the multifaceted nature of learning in complex learning environments, especially when it involves helping an entire class of students learn successfully. But, by broadening the scope of scaffolding, have we generalized it too much? Have we stripped the notion off its original meaning? Where should we draw the line between 'support' and 'scaffolding'? Is all support scaffolding? In this paper, we argue for a careful re-examination of the notion of scaffolding, particularly in the field of the learning sciences.

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[1] By complex learning environments, we mean classroom environments that are based on socio-constructivist approaches to learning, characterized by learning by doing, collaboration and negotiation.

While acknowledging that the original notion of scaffolding that described the one-on-one interactions between an adult and child is not adequate for describing the complex nature of learning in a classroom, we emphasize that some of the critical elements of scaffolding are missing in the evolved notion. We discuss the key aspects of scaffolding and how we can design and implement these features in the changed context of scaffolding classroom communities.

Describing scaffolding

Scaffolding has been 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." The notion of scaffolding has been linked to the work of soviet psychologist Lev Vygotsky. However, Vygotsky never used the term scaffolding, but believed that learning first occurs at the social or interindividual level and emphasized the role of social interactions as being crucial to cognitive development. Thus, according to Vygotsky (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" (Vygotksy, 1978). Enabling the learner to bridge this gap between the actual and the potential depends on the resources or the kind of support that is provided. As Stone (1998) has pointed out, the original description of scaffolding by Wood et al. was largely pragmatic, and it was later (Bruner, 1985; Cazden , 1979, cited in Stone, 1998), that the notion of scaffolding was linked with 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, carry out a task or achieve a goal that she would not be able to achieve on 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.

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 "which would be beyond his unassisted efforts" (Wood et al. 1976), and describes a support that "can be easily disassembled when no longer needed." But an important difference, as Lepper, Drake, & O'Donnell-Johnson (1997) have 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. In the next few paragraphs, we have summarized some of the key aspects of scaffolding provided by an adult or an expert (e.g. Langer & Applebee, 1986; Palincsar & Brown, 1984; Reid, 1998; Stone, 1998).

Key Features of Scaffolding

The original notion of scaffolding assumed that a single more knowledgeable person, such as a parent or a teacher helps an individual learner, providing him or her with exactly the help he/she needs to move forward (e.g., Bruner, 1975, Wood et al. 1976). 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. In this description, the expert is the 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 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 then, the adult's role has perceptual, cognitive as well as affective components (Stone, 1998).

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 by herself, *intersubjectivity* (Rogoff, 1990; Wertsch, 1985) or a shared understanding of the activity is of critical importance. 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 she needs to accomplish. This helps provide motivation for the child to complete the task. The adult/expert has 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).

A 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, the subgoals that need to be accomplished, but should also have knowledge of the child's capabilities that change as the instruction progresses.

> 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 (Wood et al. 1976, p. 97).

The ongoing diagnosis leads to a "careful calibration of support" (Stone, 1998) so that the adult is able to provide "graduated assistance" (Stone, 1998) of different types. The adult draws from a repertoire of methods and strategies, constantly fine-tuning the support based on the child's changing knowledge and skills, i.e., following a "moving zone of proximal development" (Greenfield, 1999). Thus, the amount and types of strategies are different not only for different learners with different levels of expertise, 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).

The ongoing assessment and adaptation of support is attained through the *dialogic and interactive* nature of scaffolded instruction. The dialogic interactions (Reid, 1998), so beautifully embodied in the reciprocal teaching studies (Brown & Palincsar, 1987; Palincsar & Brown, 1984), enable the teacher an ongoing assessment of the student's understanding as well as allowing students to play a role in negotiating the interactions. The dialogue between the student and the adult/expert is extremely important because it allows students to "exercise some control over the dynamics of the situation, and to negotiate the instructional interaction" (Reid, 1998) based on their evolving understanding. It also enables the adult to monitor progress, provide appropriate support and eventually fade the support so that the learner is now able to function on her own.

The final feature of scaffolding is *fading* the support provided to the learner so that the learner is now in control and is *taking responsibility* for her learning. Vygotsky believed 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 towards independent activity. According to Vygotsky, internalization is "far from being a mechanical operation". In Wood et al.'s original description, what is important about the transfer of responsibility is that the child has not only learned how to complete a specific task, but successful scaffolding entails that the child has also abstracted the *process* of completing the particular activity and is able to generalize this understanding to other similar tasks.

These key features, viz., intersubjectivity, ongoing diagnosis, tailored assistance and fading are attained in the dynamic, flexible scaffolding that an adult provides to a child. As we move the notion of scaffolding into classroom communities, the individualized support is not possible. Scaffolding has therefore evolved to include multiple formats providing multiple affordances.

Scaffolding classroom communities: Multiple modes, multiple affordances

In recent years, there has been an upsurge of approaches based on a socio-constructivist framework to help students learn science and math. For example, design activities are being used as a means to promote science learning (Baumgartner & Reiser, 1998; Harel, 1991; Kafai, 1994; Kolodner, 1997; Lehrer & Romberg, 1996; Puntambekar & Kolodner, 1998). Inquiry and project-based approaches are also being used to help students learn how to formulate questions, and to design and implement investigations (Blumenfeld et al., 1991; Hoffman, Kupperman, & Wallace, 1997; Krajcik, Blumenfeld, Marx, & Soloway, 1991). Many of these approaches are based on a socio-constructivist model (Vygotsky, 1978; Wertsch, Mcnamee, McLare, & Budwig, 1980) emphasizing that learning occurs in a rich social context, marked by interaction, negotiation, articulation and collaboration. As such, the notion of scaffolding is now increasingly being used to describe the support provided to students to learn successfully in such environments. However, the original notion of scaffolding in which a single more knowledgeable person helps an individual learner, providing him or her with exactly the help he/she needs to move forward, is not adequate to explain the scaffolding in a complex, interactive classroom. Classroom situations involving many students do not allow for the fine-tuned, sensitive, personalized exchange that occurs in a one-on-one situation (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 scaffold each other. In the field of the learning sciences, the notion of scaffolding has therefore evolved to describe the support provided in multiple modes and tools with different affordances.

We have summarized the change in the notion of scaffolding in Table 1. The evolved notion of scaffolding has four main components. First, instead of a single knowledgeable person proving support, we now have distributed expertise in which peers scaffold each other, and resources as well as the learning environment itself is redesigned to provide motivation as well as support. Second, because some of the support is being provided through tools, computer-based or otherwise, the dynamic assessment that is so important to scaffolding as described in the original notion, is no longer possible. Third, in many instances, the current notion of scaffolding, especially in classrooms, focuses on providing "blanket scaffolding" – i.e., the amount and type of support is same for everyone. Lastly, there is now more focus on scaffolding skills and processes of learning. We will elaborate on each of these in this section as we discuss some of the recent attempts at designing and implementing scaffolding in complex environments.

Original notion of scaffolding	**Evolved (current) notion of scaffolding**
• Single more knowledgeable person, provides motivation by sharing a common goal, provides support to complete the task • Multimodal assistance provided by a single individual	• Authentic task often embedded in the environment, provides motivation • Distributed expertise – support is not necessarily provided by the more knowledgeable person, but by peers as well

	• Assistance of different types is distributed across many agents, tools and resources
• Dynamic scaffolding - Ongoing assessment of the learner (individual)	• Passive support – Ongoing diagnosis by peers and or software is not necessarily be undertaken
• Adaptive scaffolding - Support is calibrated and sensitive to the changing needs of the learner • Eventual fading of scaffolding as the students becomes capable of independent activity	• Blanket "scaffolding" – support (especially in tools) is the same for all students • In most cases support is permanent and unchanging
• Scaffolding is provided both for domain knowledge as well as skills	• Support is mainly provided for skills and processes

Table 1: Evolution of the notion of scaffolding

An important feature of scaffolding is the *shared understanding* of a common goal that provides motivation to students to engage in the task. While 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. Enabling contexts (Hannafin, Land, & Oliver, 1999), such as those provided by the anchors in the form of video vignettes in the Jasper series (CTGV., 1990), or an authentic task (Palincsar, 1998), or by incorporating staging activities as in the BGuILE curriculum (Reiser, 2001), not only provide students with the motivation for engaging in the activities but also create a shared knowledge of the task or problem that they are required to solve. Another interesting way to attain shared understanding is in the Learning by Design™ (LBD) curriculum, in which students work through an entire unit, the launcher unit (Holbrook & Kolodner, 2000), that creates enthusiasm and engagement and also scaffolds the building of skills such as collaboration, articulation, critiquing, etc. that students will be required to use in other LBD units.

One of the most important aspects of providing scaffolding in a classroom is the support that students provide each other as they engage in the process of inquiry, design and investigations. In contrast to the adult being the expert in the traditional notion of scaffolding, students support each other through their interactions. Brown et al. (1993) emphasized the multidimensional nature of the interactions in a classroom embodying the communities of learners approach. In this environment, learners "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." *Expertise is therefore distributed* amongst all participants, who serve as cognitive apprentices (Collins, Brown, & Newman, 1989) supporting and critiquing each other, justifying views and opinions, and offering suggestions and explanations. The teacher's role changes from that of being a knowledge giver to a facilitator of a community in which students engage in reasoning and justification, eventually helping them to adopt these crucial skills as “part of their personal repertoire” (Brown and Campione, 1990). Pea (1994) described the ‘transformative’ nature of such interactions, in which students attain a greater level of expertise as the dialogue progresses, and both students and teachers co-construct knowledge.

This shared understanding occurs in a classroom as the tools, agents (teachers, peers) and resources in the environment support multiple zones of proximal development. Students learn at their own pace and scaffolding is provided not only by the teacher, but also by peers as well as artifacts and resources (Brown et al., 1993). 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 and Bereiter, 1994), WebSMILE (Guzdial, 1997), and Speakeasy (Hoadley & Linn, 2000) provide opportunities for asynchronous discussions. These tools have been found to help students to delve deeper into important scientific issues (Scardamalia and Bereiter, 1994), to provide more scientific justifications for their designs (Puntambekar, Nagel & Kolodner, 1997), and to generate conceptually richer elaborations (Hsi & Hoadley, 1997). In addition, tools have also been used to foster synchronous collaboration as students engage in design or inquiry. Tools such as Progress Portfolio (Loh et al., 1998), Sensemaker (Bell & Davis, 1996) and the Group Design Diaries (Puntambekar et al., 1997) support student learning by providing prompts that enable them to think about the processes and reflect on their learning, while at the same time they encourage dialogue among groups of students interacting with the tools. The Collaboratory Notebook used in the CoVis project

(Edelson, Gomez, Polman, Gordin, & Fishman, 1994) provides students with a collaborative environment and supports scientific reasoning and inquiry skills. Classroom events such as “Pin-up sessions” and design discussions (Kolodner et al., 2002) enable students to share, review and critique design ideas. 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.

Since students learn at different rates in a complex learning environment, within multiple zones of proximal development, *tools, resources,* and *artifacts* are being used as scaffolds in addition to the adult (teacher) or a more capable peer. Tools and resources are not only useful for promoting dialogue and interactions, but for demonstrating “relevant aspects of the task or strategies and making covert processes visible (Collins, Brown & Newman, 1989; Linn, 1998). For example, students learning in a design-based classroom require guidance for the several activities that they need to carry out in order to successfully complete a complex task. In a learning by design classroom, designing provides students with motivation and rich affordances for learning and applying science content. However, it is not always easy for middle-school students and teachers to participate in and learn successfully from design activities. Design is a complex process, encompassing many skills and activities. Students need support to successfully execute the various activities involved in designing – analyzing the situation to understand the problems and issues that need to be addressed, gathering information, generating alternative solutions, generating criteria to evaluate solutions, thinking about trade-offs, and justifying choices. Similar challenges are present in a project-based or a problem-based classroom. In such environments, software or paper tools are increasingly being used to provide procedural scaffolding so that the teacher is free to provide conceptual scaffolding (Bell & Davis, 1996). These tools are designed to provide students with assistance as they work on their own or in small groups, on complex problems that they are unable to solve on their own. Tools can provide students with support for solving problems, for the processes in completing an activity or for understanding the domain.

For example, based on the scaffolded knowledge integration framework, the Knowledge Integration Environment, KIE, (Linn, 1998), 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 supports the scientific inquiry process by making thinking visible (Linn, 1998). One of the tools from KIE, the Sensemaker, helps students to develop scientific arguments by scaffolding the process of constructing an argument. Sensemaker makes the process visible and encourages students to reflect on the process. In addition, it also allows for peer-to-peer scaffolding as "students working on the joint construction of a Sensemaker argument often engage in productive discussion"(Bell, 1997). Another component of KIE is the scaffolding provided by the online guidance system, Mildred. This tool provides students with scaffolding at four levels – the big picture, what to do, how to do it and things to think about. Prompts in KIE include activity hints (specific prompts to help students in making decisions), evidence hints as well as metacognitive/self monitoring hints. Such hints and questions are important as students reflect on their own or to promote dialogue when students work in small groups.

Another tool, the Design Diary (Puntambekar & Kolodner, 1998; 2002), is a paper-and pencil tool that has been used in the Learning by design (Kolodner et al., 2002) classrooms. The Design Diary has pages associated with the major activities and products of the design process. Each page in the Design Diary has prompts to help students carry out its associated design step and write down important information. For example, during problem understanding, students are asked to restate the problem in their own words. Prompts for choosing between alternative solutions ask them to identify the criteria against which they would evaluate possible solutions and to state why they thought these criteria were important. The diaries also have, on some pages, examples of good and not-so-good responses as models of what students are to think about and articulate. Prompts in the diaries help students to reflect on their design activities and articulate their thought and ideas.

Opportunities for feedback and reflection are also provided in the SMART environment (Vye et al., 1998). STAR LEGACY (Schwartz, Lin, Brophy, & Bransford, 1999) provides a visual representation of the learning cycle to help students with the steps involved. This representation, according to Schwartz et al., is designed to help both students and teachers understand where they are in the learning cycle. After reviewing the initial challenge in video format, this cycle leads students through the processes of generating ideas, considering multiple perspectives, researching and revising, testing their knowledge as they learn, and finally going public. In addition, the look ahead and reflect back option allows students to revisit the learning context and learning goals.

The scaffolding in some of the examples discussed above is blanket “scaffolding” (i.e., it is same for all students). In addition, the prompts are fairly passive and do not respond to the changing skill levels of the learner. A slightly more interactive approach can be found in tools such as Model-It based on the ‘learner-centered design’ (LCD) approach (Jackson et al., 1998). In this environment, three types of scaffolding are provided – reflective scaffolding, intrinsic scaffolding and supportive scaffolding. Reflective scaffolding promotes reflection on the task by providing prompts. The last category, task-focused scaffolding, supports the learner by changing the task itself, by making the advanced features of the task unavailable. Supportive scaffolding refers to specific help that the students are provided to complete the task – examples, what to do next hints, etc. Fading of scaffolding is accomplished by a simple mechanism – a ‘stop reminding me’ button that the student can choose when she does not need the hints, i.e., fading is not automatic but has to be explicitly initiated by the student.

Fading is achieved in Ecolab (Luckin, 1998) by using a learner model and varying the amount of control based on the system’s beliefs about the child’s learning. However, in most other environments described in this paper, the scaffolds are permanent and unchanging. Moreover, the scaffolding provided by tools and resources typically assist students with the procedural aspects of an activity, or help them reflect and articulate. As mentioned earlier, in contrast to the scaffolding provided by an expert, the scaffolding in tools is passive, and in most cases is uniformly presented to all learners regardless of their ability, specific difficulties, or situational variations.

Tools have also been designed to *scaffold the task* itself. In her Eco-Lab[2] environment, Luckin (1998) has implemented task-focused scaffolding by varying the difficulty of the activities and by varying the complexity of the environment itself. Jackson et al.'s (1998) intrinsic scaffolding also provides scaffolding for the task, by making the complex aspects of the task unavailable to novice learners. Burton, Brown & Fischer (1999) discuss a paradigm that they call "Increasingly Complex Microworlds," in which a student is exposed to a sequence of environments (microworlds) in which the tasks become increasingly complex. While it may be argued that task-focused scaffolding is in some ways similar to the Skinnerian concept of shaping – the major difference is that within each task, a learner may be scaffolded within his or her ZPD – so that the learner is provided with support as well as the challenge to complete the task (Roehler & Cantlon, 1997).

Many of the current approaches focus on scaffolding the processes that students need to understand better in order to learn successfully in a complex environment. This is significantly different from the scaffolding that an expert might provide to a single student as discussed in the early approaches to scaffolding. Whether in the early parent-child studies or in teacher-student studies, or in the apprenticeship studies where an expert modeled a skill for novices, a key aspect of scaffolding has been the fact that the

[2] Although we have included Ecolab in this discussion, we would like to note that Ecolab provides scaffolding within the ZPD of the learner and also fades the scaffolding based on a learner model.

adult or the expert is also the domain expert. However, many current tools built for scaffolding focus on helping students move forward with their projects and activities, by providing them with options about what to do next, providing hints relating to those options and by helping them reflect on their learning. One of the exceptions to this approach is the BGuILE environment that provides domain-based scaffolding to help students investigate the different aspects of a complex phenomenon. As described by Reiser et al. (2001), BGuILE's software tools explicitly represent domain specific theories and strategies in ways that guide students' inquiry processes and emphasize general, epistemological goals for their inquiry products.

Recent approaches have also examined the role of the teacher as a facilitator of small groups as well as the whole class, as critical to successful learning in complex environments. A teacher leading a whole class discussion has to take into consideration "a whole group of students who are at varying places in their learning" (Hogan, 1997). These whole-class discussions might happen during several key stages throughout the course of a unit (Puntambekar & Kolodner, 2002). Very often, the kinds of experiences that students have in small groups are very different for each group, depending on their investigation paths and the specific stage at which the teacher interacts with them (Tabak and Reiser, 1997). This means orchestrating the classroom in ways that ensures that individual or small-group work that students might do be formally used in whole-class discussions, and that there be more opportunities for small groups to share with the class the ideas they are formulating or testing. In their analysis of interactions in socio-constructivist classrooms where teachers followed the literacy cycle to help students learn to read and write, Roehler and Cantlon (1997) have described the *types* of scaffolding that teachers provide during "learning conversations." They found that teachers offer explanations, invite student participation, verify and clarify student understandings, model desired behaviors and invite students to contribute clues about how to complete the task. Hogan & Pressley (1997) described the teacher's role "within a community of inquiry" as being " not so much to execute a set of specific strategies, but rather to organize the learning environment to establish an underlying culture that centers around thinking together with students." They have summarized ten types of teacher statements that can prompt student thinking: Framing a problem or articulating a goal, encouraging attention to conflicts and differences of opinion, refocusing the discussion, inviting interaction of ideas, prompting refinement of language, turning question back to its owner, communicating standards for explanations, asking for elaborations, clarifications and finally restating or summarizing student statements. The teacher therefore plays a crucial role in making students' private learning opportunities public and in moving them from "local" to "global" understanding (Tabak and Reiser, 1997).

It is therefore clear that in a complex environment of the classroom, not all of the scaffolding can be provided with any one tool or person. Support is now being provided in multiple forms. Puntambekar & Kolodner (2002) have discussed the notion of *distributed scaffolding*, to describe the support that is provided in multiple forms by many tools and agents that play a role in learning (for example - the teacher, peers, software and paper and pencil tools). To help students learn successfully in a classroom, a *system of scaffolding* is required that integrates the activities that students have to carry out. Such a system is indeed valuable for supporting classroom communities learn better. However, not all the support provided by a tool or resource can be called scaffolding. If we do that, then we have overlooked some of the key elements of scaffolding.

Evolved notion of scaffolding: What have we gained and what have we missed?

As the discussion in the earlier sections points out, the notion of scaffolding has evolved since its original conception, and has changed considerably in the last decade. While recent approaches have helped us understand the kinds of support that we need to design to help classroom communities learn successfully, there have also been some aspects of scaffolding that have been difficult to achieve because of the reality of scaffolding in a classroom. Therefore, as we move towards implementing learning environments based on social constructivist theories, it is important to examine this change and to consider what is unique about, and what we are missing in the current implementations of scaffolding.

Our understanding of helping students learn in an interactive environment of a classroom is now substantially enriched. While there might have been limitations to the types and amount 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. Tools such as those described in the previous section have been designed to provide support to individual students and small groups as they engage in complex activities. These approaches have also helped us understand the different types of support that students need in order to learn successfully in complex environments. Tools and environments that provide domain specific, procedural, metacognitive as well as reflective scaffolding have been designed, providing an array of methods for helping students learn in a socio-constructivist classroom. Software tools that force “students to encounter important ideas” (Reiser, 2002) have helped externalize processes and representations that would otherwise be tacit.

Scaffolding has also evolved to include a careful orchestration of the environment – both software environments as well as the classroom environment. In the traditional use of the metaphor, there was an emphasis on scaffolding the learner. However, as the learning sciences community designs complex environments to help students learn, there has been a realization of the need to provide not only learner-focused scaffolding but also task-focused scaffolding (Luckin, 1998), where the task or the activity itself is varied based on the current state of the learner. Approaches such as pin-up sessions, presentations by groups of students to share their ideas, and prompting and questioning by teachers have helped in establishing a culture of questioning and negotiation that can serve as a powerful tool for learning. Moreover, the notions of distributed scaffolding, and the complementary roles played by the tools, small group and whole class interactions and teacher-led discussions have provided promising new directions for designing scaffolding for a community of learners.

However, in many instances which are now being described as scaffolding, there seem to be some critical aspects of scaffolding that we may have overlooked, since we are now more concerned with designing scaffolding for a whole class of students or for a community of learners. To the extent that scaffolding is based on knowledge of the task and the difficulties that students have, and to the extent that tools, resources and activities can be built to support student learning, we have been successful in addressing the difficulties that students have by building tools and resources. However, if the tools that we have built are permanent and unchanging, they can be described as "permanent supports" (Roehler and Cantlon, 1997) – tools that help provide structure and consistency, by highlighting the aspects of the tasks that students should focus on. While this is by no means trivial, we would like to emphasize that a 'support' becomes a 'scaffold' only when it is adaptive, based on an ongoing diagnosis of student learning and helps students to eventually internalize the knowledge and skills and gain control of their learning. We therefore need to move forward and examine what we have missed so that we can design effective scaffolding. We have summarized four elements of scaffolding that have changed as we have moved toward scaffolding classroom communities.

First, the original notion of scaffolding focused on helping the learner in her ZPD, which required an *ongoing diagnosis* of the learner's changing knowledge and skills. As we look at implementations of scaffolding in the classroom, where peers scaffold each other or the scaffolding is embedded in the software or other tools, we find that this critical aspect of scaffolding is difficult to achieve. The ongoing assessment that is so critical to providing the right amount of support so that the learner is challenged as well as supported is not accomplished by designing "blanket scaffolding" in which all learners get the "same" scaffolding, contradicting the very notion of scaffolding.

Second, as we move the notion of scaffolding into the classroom, the *dynamic* and *adaptive* support provided to an individual learner by a more capable adult is no longer available. Although peers may scaffold each other to some degree, they 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 the bi-directional, 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 maintains 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 her specific needs, which is not possible in peer interactions. It is therefore difficult to provide the adaptive and dynamic support that is tailored to every individual in a classroom situation. Tools can help to some extent; however, software support with the exception of some tools is not necessarily adaptive.

Third, good scaffolding implies that the student is now able to perform the tasks on her own, and there is a *transfer of responsibility* from the “scaffolder” to the “scaffoldee.” This aspect of scaffolding has perhaps been overlooked in the many environments that we discussed in the earlier section. Because of the passive nature of the prompts and the reality of learning in a real classroom, it is indeed difficult to assess whether there has been a transfer of responsibility and students have in fact gained the knowledge and the skills that were being scaffolded. Although a lot of the work in the classroom might be done in a group, it is important to understand what students have learned, in order to understand the effectiveness of the tools, or the curriculum. Brown et al. (1993), based on Rogoff (1990) prefer to use the term 'mutual appropriation' instead of internalization to emphasize the multidimensional nature of the interactions in a classroom embodying the communities of learners approach. In such an environment, there is collaboration, interaction and negotiation, and students learn from each other. Brown et al. argue that the "appropriation" of ideas in such an environment is multidirectional and there are multiple zones of proximal development in which students learn at different rates and appropriate ideas and skills based on their current zones of proximal development at any given time. The notion of mutual appropriation suggests that students will appropriate ideas based on their ZPDs, but for scaffolding to be successful, we argue that it is important to understand the extent of such appropriation.

Fourth, in many of the systems described in the earlier section, the scaffolding that is provided is based on an analysis of the process. Students are given support, many a time procedural support, to help them with the subgoal or activities that are necessary to complete a task. As we understand from the earlier notion of scaffolding, when an adult or an expert scaffolds a learner, the dialogue that ensues is based in the domain or the subject matter that the student is learning, because the adult in most instances is also a domain expert. The same is true of apprenticeship situations when, for example, a novice is learning by observing the master weaver (Greenfield, 1999). This may not occur in a classroom community, although some students might come with more knowledge about the domain than others might. Opportunities where a teacher/expert can provide more domain specific support therefore need to be built in. In addition, domain-specific support such as that provided in the BGuILE environment is critical for helping students gain a deeper understanding of the subject.

Thus, although the notion of scaffolding has evolved and our understanding of providing support in multiple formats is now enriched, we need to think about the critical elements that we are missing, such as the ongoing diagnosis of student learning, the careful calibration of support, providing more domain-specific help and transfer of responsibility. In the next section, we present some suggestions to address these issues.

Moving forward with scaffolding classroom communities

As indicated in the beginning of the paper, our aim in this paper is to discuss how the notion of scaffolding has evolved and to initiate dialogue to explore the aspects of scaffolding that we need to further research. Therefore, in this section we present some directions that we need to consider to design and implement scaffolding in complex learning environments. These are by no means exhaustive and we invite the learning sciences community to continue the dialogue about other directions.

Shifting the focus of ongoing diagnosis to the group as a unit: In many of the approaches discussed earlier, students work in small groups to solve a problem, work on a project or design an artifact. The support provided in the examples discussed earlier, is designed to help groups of learners as they engage in a complex task. As such, the focus of ongoing diagnosis needs to shift to the group as a unit. When students interact with each other in a group, we find that the more able ones support the less able learners and the tools and resources facilitate this. The adult or the teacher who would otherwise have been engaged in a one-on-one interaction with a student now has to interact with the group and keep track of the group's progress over a period of time. This will enable her to understand whether the group is indeed moving forward, and provide opportunities for the teacher to find out about group members' misconceptions if any. As the teacher monitors different groups in the class, the common misconceptions across groups might also be recognized and brought up in whole-class discussions. In addition to misconceptions, the new insights that some of the groups might attain can also be shared with the whole class. One of the examples that come to mind in monitoring the progress of the groups is the case of the 'sponges' described by Scardamalia and Bereiter (1994). While students were engaged in online discussions, one student posted a response about the three ways of reproduction in sponges, and a discussion about deeper issues of evolution followed, with an insight into the structural simplicity of sponges and its relationship to the reproductive processes. Although this is a great example of peers learning from each other, a teacher monitoring this discussion can bring it to the notice of the whole class. The role of the teacher in monitoring the progress of groups and bringing group ideas to the attention of the whole class is now critical. As one teacher recently pointed out to us "after each class

I keep a journal of where my different groups are in terms of their learning and understanding so that I can start the next day's work with a discussion of the difficulties or any new ideas that came up." Another way in which we are trying to help understand where the groups are in terms of their understanding is by using computer generated log files of students' navigation paths (Kulikowich & Young, 2001). By analyzing the navigation paths as students traverse through an online resource designed to help students understand the relationships among concepts (Puntambekar, Stylianou and Jin, 2001), and looking for patterns, a teacher can be alerted to unique aspects that stand out. We are working on a system where the teacher can be alerted to the most frequently visited concepts, most frequent transitions, unusually long or short amounts of time spent on concepts, etc. The teacher can then integrate these observations with the progress of groups in the classroom and she can then use all of the observations to guide whole class discussions or small group facilitation. Ways to keep track of the dialogue among groups, such as using an online discussion tool, or capturing group conversations, can help a teacher as well as a researcher examine a group's progress over time and analyze whether students' dialogue shows an increasing depth of knowledge.

Building Redundancy and Fading: 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. In her studies of weavers in Mexico, Greenfield (1984) also emphasized the importance of the multimodal assistance that mothers provided to their daughters who were learning to weave. In the complex environment of the classroom, there are multiple

ZPDs that teachers/researchers have to take into consideration while building scaffolding. It is not possible for one person to provide support for the multiple students learning at different rates within their ZPDs. Building redundancy can therefore make up for the lack of graduated assistance if multiple ways and multiple levels of scaffolding are tailored to the multiple ZPDs that are found in any classroom. When scaffolding is provided in multiple formats, there are more chances for students to notice and take advantages of the environment's affordances. For example, recognizing the need to reflect is particularly difficult when students are working hard on a hands-on activity (indeed, taking time to reflect is hard for anybody in the flow of working on an exciting hands-on activity). Paper-and-pencil and electronic scaffolding cannot help students recognize that need; rather, they seem to need to be interrupted from their activities to think about what they are doing. When scaffolding is distributed across tools and agents in the environment in a systematic way, such difficulties can be dealt with from a variety of perspectives (Puntambekar & Kolodner, 2002). Multiple opportunities are important too. Students who fail to understand a prompt in a paper or software tool may need another opportunity to be scaffolded during a small group session when a peer asks the same question that is in a prompt but uses different words or during a whole-class discussion when another student explains how he/she accomplished some task.

An issue to consider while building redundancy is to build tools that not only provide support for the process, but also provide scaffolding for a specific domain. Tools and resources (e.g. Digital library, CoMPASS) may be integrated into the environment that can help students with their domain related questions. CoMPASS (Puntambekar, 2000) provides conceptual support by using dynamic concept maps that show the relationships among concepts. It enables students to see a particular concept or principle through many different ‘views’, enabling them to understand the multiple relationships among concepts.

Inherent in the notion of scaffolding is the goal that students will be capable of independent activity when the scaffolds are removed. Closely coupled with the ongoing diagnosis of learning is the notion of *fading* scaffolding as students become more independent and capable of taking responsibility for their learning. Our aim in designing support is to ascertain that students learn the necessary domain and skills and are able to generalize them to other contexts.

An important aspect of scaffolding in a classroom is that it is hard to achieve the kind of adaptive support eventually leading to fading that is possible in a one-on-one situation. In the reciprocal teaching studies, students took responsibility for leading the group discussion as they developed the skills. Another example is the system MIST (Puntambekar & du Boulay, 1997) in which the system keeps track of the learning paths of pairs of learners and advises one to support the other based on these paths. Although these systems are a step in the direction of providing more adaptive support, we need to find other ways of achieving adaptivity so that students of all abilities receive the scaffolding that they need. By building redundancy into the scaffolding, and designing tools with multiple layers of scaffolding such as in Ecolab (Luckin, 1998), and designing the environment with a suite of such tools, some adaptivity and fading can be achieved.

We would like to go back to Wood et al.'s original description of a 'theory of the task' and 'a theory of the tutee', as crucial to building effective scaffolding. In order to build tools based on multiple ZPDs (theories of the multiple tutees), we need to conduct extensive studies of the difficulties that students have in a particular situation and revise that knowledge as we move forward. 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 scaffolds may be removed, thereby achieving fading.

Engineering the classroom environment for successful learning: The biggest challenge that we face is the orchestration of the tools and activities so that the affordances of each are taken advantage of. Although studies involving distributed scaffolding are a step in the direction, we need more studies about what works and what does not in a classroom environment. 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. Effective scaffolding therefore needs to be distributed, integrated, and multiple, so that students have more chances to notice and take advantages 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.

As we move forward, we need to design more ways for peer interactions and weaving in whole class activities and small group interactions so that they complement each other, and provide opportunities for dialogue and interactions. One way to achieve more dialogue is to include many opportunities for whole class discussions or group reviews such as “pin-up sessions”. Pin-up sessions enable students to present their ideas, models, and designs in progress, and whole-class discussions at strategic times in the orchestration, help to bring issues to the attention of all the students in the class. For each, it is extremely important to decide on appropriate points when they should be held, and the kinds of presentations and discussions that should be their focus.

Brown and Campione (1994) and Brown et al. (1993) discuss 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….If students are apprentice learners, the teacher is the master craftsperson of learning whom they must emulate. In this mode, the teacher models …through thought and real experimentation (Brown et al. 1993, p. 189).

As we move forward, we need to better understand effective teaching practices, especially the kind of support that teachers provide during small group and whole class discussions in an interactive environment, so that we can build better professional development activities and scaffolding for teachers.

Conclusion

In this paper, 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 evolved in the last two decades. While it is important for the notion of scaffolding (or any notion for that matter) to evolve and be enriched, it is at the same time necessary that we do not overlook the essence of that notion. Although the current notion of scaffolding has helped us understand 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 understand better the learning that is taking place during peer conversations, during whole class discussions to be able to integrate all these activities in a seamless manner.

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